Report of the
Defense Science Board Task Force
on
Integrated Fire Support in the Battlespace

October 2004

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OFFICE OF THE SECRETARY OF DEFENSE
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DEFENSE SCIENCE BOARD

MEMROANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Integrated Fire Support in the Battlespace

I am pleased to forward the final report of the DSB Task Force on Integrated Fire Support in the Battlespace. The Task Force was asked to apply the methodology developed during the 2001 Defense Science Board Precision Targeting Summer Study to those fires directed by the on scene commander which provide support to the fielded forces.

The report concluded that both unguided and precision weapons are needed to support maneuver warfare. To support integrated fire support in the battlespace, the Task Force makes several recommendation in the following areas:

- New precision discriminatory weapons require the continued development of MEMS based INS/GPS guidance capabilities, low cost seekers and data links. Without these technologies, engagement of hard and moving targets will not be possible.
- The on scene commander requires improved organic ISR assets including but not limited to tactical UAVs and man-portable targeting systems. These assets coupled with improved blue force tracking will provided the necessary clarity to the Situational Awareness picture to allow precision engagement.
- Continued support of the GRIDLOCK ACTD is needed. This program has the potential to link national, operational and tactical ISR data to provide highly accurate target locations.
- A truly integrated fire control system, which incorporates all the service requirements, is needed to enable the on scene commander to employ his assets most effectively on the battlefield.

I endorse all of the Task Force's recommendations and encourage you to review the Task Force report.

William Schneider, Jr.

William Schneider, Jr.
DSB Chairman

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DEFENSE SCIENCE BOARD

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Task Force on Integrated Fire Support in the Battlespace

The Integrated Fire Support in the Battlespace Task Force applies the methodology developed in the 2001 Defense Science Board Summer Study on Precision Targeting to shorter range ground and sea launched weapon systems which operate under the control of the on scene commander and are designed to provide fires, both organic and inorganic, in support of maneuver forces.

This Task Force was asked to assess adequacy of current and proposed munitions; adequacy of Intelligence, Surveillance and Reconnaissance (ISR) techniques and mechanisms to meet the needs of the tactical and operational battlefield forces; adequacy of battlefield command and control; impediments to fully integrated Air, Land and Sea fire support; and need for predictive engagement tools and derived intelligence products to guide the battlefield commander in the use of forces to shape the outcome.

In the course of its deliberations, the Task Force reached the following conclusions:

- A mix of unguided unitary weapons and precision discriminatory weapons will be needed to provide the full range of options for ground fires in support of maneuver warfare under conditions where the Rules of Engagement (ROEs) are becoming more restrictive. To support this end, MEMS-based INS/GPS guidance systems and an updated Joint Munitions Effectiveness Manual (JMEM) will be needed. Additionally, low-cost seekers and data links will be required for hard (tanks, APCs) and moving targets.
- We must be able to accurately detect, locate, identify and assess post attack damage on targets if precision discriminatory weapons are to be effectively utilized. Continued development and deployment of new organic tactical ISR assets and improvements to vehicle-mounted and man-portable targeting systems are needed. Critical to the development of these organic ISR and targeting assets is the need to reduce the target location error produced by the sensors to a level comparable to the weapon guidance errors for precision munitions.

  It is becoming more and more difficult to provide positive identification of enemy and neutral targets in the battlespace. Development of a blue force situation awareness (SA) capability will provide an accurate baseline on the location of friendly forces and thus enable a better understanding of the combat identification problem.

- A truly integrated fire support system must employ an approach to command and control that ensures that the best available targeting and attack resources are available to the maneuver commander. The primary challenge is to transform the current collection of multi-Service fire support functions into a net-centric system. A Joint Integrated Fire Support System (JIFSS) is proposed which more tightly integrates the Service-based components and includes decision support tools.

Vince Vitto

Mr. Vincent Vitto, Co- Chair

Bob Nesbit

Mr. Robert Nesbit. Co- Chair

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

1.1 Task Force Background and Approach

In 2001, the Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)) directed the Defense Science Board (DSB) to study the precision targeting of air-delivered munitions. The results of the 2001 Task Force were well-received within Office of the Secretary of Defense (OSD), and in June 2003, USD(AT&L) directed the DSB to study the closely related topic of "integrated fire support in the battlespace." In this new study the 2003 Task Force applied an approach and methodology similar to the 2001 effort but focused instead on ground-based fires, sea-based fires, and close-air support.

As directed in its terms of reference (TOR), the 2003 Task Force assessed the following:

- The adequacy of current and proposed munitions,
- The timeliness and accuracy of ISR systems,
- The adequacy of battlefield C^3 systems, and
- Impediments to integrated fires.[1]

From October 2003 through April 2004, the Task Force met monthly to gather information. Table 1 summarizes the topics the Task Force discussed.[2]

• Integrated Fire Support	• ISR Architecture	• MIDB Status
• Future Combat Systems	• Joint Fires Network	• Army Maneuver and Fire Support
• C^4ISR for FCS	• Joint Targeting Toolbox	• Joint Close Air Support
• Single Int. Ground Picture	• Surface Fires CONOPS	• U.S.MC Air Support
• DCGS – Army	• DD(X) Program	• Jacknife ACTD
• Prophet	• Advanced Gun System	• Joint Urban Operations
• Aerial Common Sensor	• ERGM/ANSR	• SOCOM Fire Support
• ATCCS	• Electromagnetic Rail Gun	• GPS Guidance
• Force XXI	• F-18 E/F and JSF	• Joint Munitions Effectiveness
• Global Broadcast	• Aviation Munitions	• Seekers and Data Links
• Army Direct Fires	• USMC Fire Support	• Emerging Communications
• Air-to-Ground Missiles	• OEF & OIF Lessons Learned	• Adaptive C^4ISR
• Close Ground Combat Missile	• JBMC^2 Roadmap	• CDMA on the Battlefield
• Precision Guided Mortar	• DCGS Integrated Backbone	• Net Fires
• Mid-Range Munition	• UAV Update	• Emerging Weapons Concepts
• Cannon Transformation	• Geospatial Intelligence	• Tactical Network Technology
• MLRS Transformation	• GRIDLOCK	• Dynamic Tactical Targeting
• Naval Fire Support	• Geopositioning Study	• Emerging C^4ISR Concepts
• FORCENet	• Airborne Targeting Cell	

Table 1-1: Topics discussed.

As the Task Force transitioned from gathering information to synthesizing and writing, it divided into three working groups: *weapons*, *sensors*, and *command and control*.

[1] See the complete terms of reference (TOR) in Appendix A.
[2] Appendix B lists the Task Force members, advisors, and support personnel; Appendix C provides detail on the briefings received.

1.2 Foundational Issues

Before we summarize the body of the report and our key recommendations, we first review a brief set of foundational issues.

Requirements for fires

Fire support is often divided into three areas: *shaping fires*, *counter strike*, and *close support fires*.

- *Shaping fires* are employed at tactical and operational depth against target sets such as command and control nodes, moving and stationary enemy armor and infantry formations, assembly areas, logistics stockpiles, staging points, and air defense assets.
- *Counter strike* is used against opposing force weapon delivery platforms such as mobile missile launchers and long-range guns. It is also used to counter command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) assets.
- *Close support fires* are employed for decisive operations against (1) armor and infantry units in contact, (2) tactical command and control, (3) forward air defense, and (4) indirect fire assets such as cannons and mortars.

A major challenge for future operations is to create synergy between maneuver and precision fires. Maneuver is designed to achieve positional advantage over the enemy by positioning forces at decisive points to achieve surprise, psychological shock, physical momentum, and massed effects. Fires are used in combination with maneuver to place the enemy in a dilemma and a position of disadvantage.

Indirect fires on the road to Baghdad

The following list summarizes observations made by Army and Marine Corps artillery battalions based on their experiences in Operation Iraqi Freedom (OIF).

- Most of the fires employed were massed fires with unguided munitions.
- These fires were judged to be quite effective in producing the desired results, although the efficiency of weapon utilization and overall integration was questionable.
- Most information on enemy force location came through direct contact with those enemy forces. Organic sensing assets were used extensively--primarily scout patrols and counter-mortar and counter-battery radars.
- Sensor information from sources beyond the organic assets was very limited. Products from imaging sensors, for example, were not generally available to the artillery units as they advanced toward Baghdad.
- Close air support was used more by the Marines than the Army. Its utility was limited by what several called an unreliable and overly complex process for requesting and coordinating fires.

- In many cases, the quality of target identification, collateral damage estimates, and bomb damage assessments were lacking. This deficiency often hampered maintaining the planned Op Tempo of the operation.
- Training of the units did not match the scale of fires and pace of operations experienced in OIF.

Targeting effectiveness examples

Using the Joint Munitions Effectiveness Manual (JMEM) model, we generated some simple examples to examine the effectiveness of indirect fires against two different target sets. These examples illustrate many of the principles we will discuss further in the body of the report.[3] Each of the three examples that follow features two cases:

1. In the first case, an array of six trucks is parked randomly in a 300 x 100m area. The desired effect is to "suppress" the unit from being able to carry out its normal functions.
2. In the second case, a single truck is situated randomly in a 300 x 100m area. The objective is to damage or destroy this single truck.

The *first example* illustrates what would happen using unguided unitary rounds with an estimated target location error (TLE) of 25m: to *suppress* the array requires 18 rounds; in contrast, to *damage or destroy* just the single unit requires 868 round (according to the model). While the JMEM model is judged to be quite conservative, even reducing the results by a factor of two leads to the same conclusion – unguided rounds by themselves are very inefficient if the objective is to impose serious damage on discreet targets

In the *second example*, we reduced the TLE to zero. The results for the first case (suppressing the entire unit) are unchanged (18 rounds). There is some improvement in the second case (damage or destroy the single unit) for the single target, but it still requires far too many rounds to be practical (520 rounds). Weapon bias and/or dispersion is the issue – not TLE.

In the *third example*, we eliminated the bias errors in the guns by using observer adjusted fire. Observer adjustment obviously has a major impact in both cases. (The first case is reduced to 12 rounds, while the second case is reduced to 45.) Weapon bias clearly was the dominant issue and can be ameliorated to a large extent by human interaction, at least in the case of soft targets.

The conclusions to be drawn from these (overly) simplistic examples are as follows:

1. Massed fires are effective for suppressing concentrated arrays of forces. The more targets in a given area, the better. Precise target location is not required.
2. Massed fires are inefficient and ineffective for high confidence destruction of a single target. To do so requires both precise target location and a precision attack mechanism.
3. Observer-adjusted fires make a huge difference in the effectiveness of current weapon systems.

[3] Chapter 2 of this report revisits these examples and illustrates them using graphics.

When looking to the future, the critical question is this: "What target sets will we be facing and what effects will we be trying to achieve?" The answer is certainly "both of the cases presented here," but it is likely that we will be facing more of the second case than has been planned for in the past. The other obvious topic is observer adjustment. Is that the way to operate in the future (are the opportunities always there) or can the requirement for forward observer (FO) exposure be supplemented or replaced with more machine-oriented precision approaches?

Today, the majority of indirect fires are unguided massed fires. That, however, will change. As we look at modern maneuver warfare and asymmetric threats and tactics (particularly operations within urban environments), we see a trend toward ever more restrictive rules of engagement (ROEs). These ROEs insist on minimizing collateral damage and blue-force fratricide and demand highly integrated, adaptive precision targeting solutions. While we will still need massed fires for certain situations (distributed target sets and fires for effect), we will also need to change procedures and weapons such that we can employ more air support and more accurate precision fires.

The question here is "How do we get there from here?" In other words, how do we evolve the weapons, improve the sensors, and enhance the command and control systems to achieve accurate, fully integrated, cost-effective fire support? The following section addresses these questions and previews the main body of the report.

1.3 Report Preview

We have divided the main body of the report into four main chapters: (1) introduction; (2) fire support weapons; (3) sensors; and (4) battle management, command, control, and communications. In the introduction, we revisit the foundational issues discussed above. We add some additional charts and tables that further illustrate the chapter's main points. In the following paragraphs, we discuss each chapter briefly in turn.

Fire support weapons

We discuss the trend toward increasingly restrictive ROEs and how this trend adds to the pressure to improve accuracy. We also discuss the value and cost of precision, which must be balanced with operational need, the nature of the target, the limits of our sensors, and the total cost-to-kill of the delivered weapon. We explore these tradeoffs in some detail and assess the utility, effectiveness, and cost-to-kill of various classes of weapons. The obvious question is whether the increased unit cost of more expensive precision weapons is offset by the decreased number of rounds required. We conclude that the transition point from a less sophisticated to a more sophisticated weapon is clear and not overly sensitive to even moderate cost variations (see page 35 for specific conclusions). In this context, we also address the need to update the JMEM and the need to balance weapon delivery error (WDE) and TLE for the type of weapon employed.

We conclude that a mix of unguided unitary weapons and precision seeker-guided discriminatory weapons will be needed to provide the full range of options for ground fires in support of maneuver warfare under conditions in which discrete target destruction becomes more the objective and ROEs become more restrictive. Development of new precision unitary weapons will require continued development of MEMS-based Inertial Navigation System/Global Positioning System (INS/GPS) guidance with improved em-

bedded global positioning system (GPS) anti-jam capability and deployment of this capability within Army and Navy acquisition programs for precision gun-launched munitions (XCALIBER, Extended Range Munition (ERM), etc.). We have also demonstrated that precision discriminatory weapons, which include a low-cost seeker and a data link in addition to the INS/GPS system, will be required for hard (tanks, armored personnel carriers (APCs), etc.) and moving targets. The accelerated development of affordable seekers and data links is also recommended to make this capability a reality. We also recognize that the availability of a seeker and data link within a discriminatory precision weapon opens up new possibilities for an organic target identification and battle damage assessment capability. Observing the target prior to and after engagement and communicating seeker imaging data via the data link would enhance the information available for target identification and battle damage assessment (BDA). We recommend serious exploration of this potential.

Sensors and targeting systems

Having a precise weapon is not enough to achieve an operational precision targeting capability; we must also be able to detect targets, locate them, identify them, and assess damage to them post-attack. We must improve sensors and targeting systems in order to improve the accuracy and effectiveness of the overall integrated fire support system. We have assessed current tactical weapon targeting, aided visual indirect targeting, combat identification and blue-force situational awareness, and timely tactical targeting and battle damage assessment. In each case, we identify technologies and approaches to improve our sensing and targeting capabilities.

Specifically, we call for the continued development and deployment of new organic tactical intelligence, surveillance, and reconnaissance (ISR) assets (Pioneer, Tactical Unmanned Aerial Vehicle (TUAV), etc.) and the need for improvements to vehicle-mounted and man-portable targeting systems. The required TLE for precision munitions must be less than 10 meters for those weapons to be effective. The current TLEs for airborne, vehicle-mounted, and man-portable systems range from tens to hundreds of meters. We identify the technology developments needed to improve these systems. We also recommend continued support for the "GRIDLOCK" Advanced Concept Technology Demonstration (ACTD) and ultimate deployment of this capability. "GRIDLOCK" holds the potential for reducing TLE provided by ISR sensors by "locking" tactical imagery to a reference precision image. We also discuss the need to extend the tactical ISR assets to allow for timely airborne visual imagery collection to enhance organic battle damage assessment.

It is becoming more and more difficult to provide positive identification of enemy and neutral targets within the complex battlespaces that we will encounter in the future. The success of precision blue-force tracking during recent operations and the continued deployment of digital communications and GPS receivers to all military personnel will make the possibility of a robust and timely precision blue force situation awareness (SA) capability a reality. We call for the development of a blue-force SA capability that will provide an accurate baseline on the location of friendly forces and thus enable a better understanding of the combat identification problem.

Battle management, command, control, and communications

A truly integrated fire support system must employ an approach to command and control that ensures that the best available targeting and attack resources across the Services are made available to the maneuver commander. The primary challenge is to transform the current collection of multi-Service fire support functions (initially conceived to operate independently) into a net-centric system. With the evolution of increasingly reliable and pervasive digital communications and fast and powerful tools for aiding commanders in decision-making and execution monitoring, it is time to rethink the approach to battle management, command, control, and communications (BMC^3) that our military employs both within and across service in supporting operations with joint fires and close air support. We have addressed a range of possible solutions to this problem, including a proposed system we call the Joint Integrated Fire Support System (JIFSS) as well as improvements to the current family of common operational pictures.

The proposed JIFSS would have Service-based components that are more tightly integrated than today. In addressing a maneuver commander's desired effects, the JIFSS decision support toolset would enable nearly continuous updates of dynamic fire support and airspace coordination and control measures to maximize both the safety of friendly forces and their flexible use of the entire battlespace. This is accomplished by establishing a common targeting picture that contains all information needed to link each target and its associated effect through a spatially oriented database that supports (1) decision making to coordinate the use of sensors to build the common picture and (2) fusion of diverse sensors for accurate TLE determination (e.g., "GRIDLOCK"). We propose development of a JIFSS that evolves by standardizing an Advanced Field Artillery Tactical Data System (AFATDS)-like capability across all Service-developed targeting systems (to include Joint Close Air Support (JCAS) coordination). We propose using the model-driven architecture (MDA) approach to ensure adherence to standards and identify the need for extensive joint exercises and simulation development to evolve this system toward a joint integrated planning and execution system for maneuver and joint forces coordination and control.

1.4 Summary of Recommendations

The following table summarizes the Task Force's key recommendations. As with the main report, we have grouped the recommendations by topic (weapons, sensors, command and control). The final column refers to the sections in the report that describe the recommendation:

Topic	Subtopic	Agent	Recommendation	Section
Weapons	**Systems cost**	**USD(AT&L)**	**Establish a systems engineering function to quantify the true total *systems* cost of delivery weapons into theater and to achieve a system balance in the acquisition process for weapons/ISR/C-3.**	**3.4**

Topic	Subtopic	Agent	Recommendation	Section
	Joint Munitions Effectiveness Manual (JMEM)	USD(AT&L)	Revitalize the JMEM process to improve usability of the JMEM toolset, to more readily accommodate today's issues such as collateral damage and to integrate efforts of JMEMs analysts and operations personnel into the design process.	3.5
	Affordable seekers	USD(AT&L)	Stand up efforts that "pull" maturing technology out of the S&T community to make affordable seekers a reality.	3.9
	Affordable data links	DARPA	Revive efforts associated with affordable data links to support the integrated fire support objectives for moving or relocatable target acquisition and battle damage assessment.	3.9
	GPS SAASM requirements	USD(AT&L)	Eliminate the SAASM requirement for integrated fire support weapons.	3.9
	Organic Battle Damage Assessment (BDA)	JFCOM	Explore useful organic level BDA offered by modern precision weapons and integrate this capability in mission planning efforts.	3.9
	Organic BDA	ASN	Revamp efforts to develop dedicated BDA assets and avoid the fragmented approaches to these dedicated sensors observed to date—approaches that have denied deployment of operationally ready technologies.	3.9
Sensors and targeting systems	GRIDLOCK	USD(AT&L)	Continue support for the GRIDLOCK ACTD and field the capability.	4.2
	GRIDLOCK	The Services	Universally adapt the GRIDLOCK capability to all tactical and theater airborne imaging sensors and make it a requirement for all new such systems.	4.2
	Tactical Unmanned Aerial Vehicles (TUAV)	ASA(ALT) and ASN(RDA)	Focus and coordinate efforts to develop tactical UAV systems for organic surveillance with improved TLE and BDA capabilities.	4.3

Topic	Subtopic	Agent	Recommendation	Section
	TUAVs	ASA(ALT) and ASN(RDA)	Establish a vigorous S&T program to develop a technical base to improve target location accuracy of TUAV, vehicular and man-portable targeting systems.	4.3
	Combat Identification (CID)	USD(AT&L) and ASD(NII)	Develop a theater-wide joint blue force CID system. - All tactical networked radios should be configured to incorporate network assisted GPS capability.	4.4
Command & control	Joint Integrated Fire Support System (JIFSS)	USD(AT&L) and ASD(NII)	Work toward developing a tactical Joint Integrated Fire Support System (JIFSS).	5.7
	Dynamic control measures	DARPA (coordinating with the Services)	Extend dynamic fire support coordination measures.	5.7
	Common targeting picture (CTP)	USD(AT&L) and ASD(NII)	Augment current family of common operational pictures (FIOPS) with richer target information.	5.7
	Tactics, techniques, and procedures (TTPs), experimentation, and training	JFCOM	Conduct joint exercises and develop simulation capabilities to enable evaluation of joint tactics enabled by integrated planning and execution of maneuver and joint fires.	5.7

Table 1-2: Summary of recommendations.

2. INTRODUCTION

2.1 Requirements for Fires

Fire support is often divided into three areas: *shaping fires*, *counter strike*, and *close support fires*.

- *Shaping fires* are employed at tactical and operational depth against target sets such as command and control nodes, moving and stationary enemy armor and infantry formations, assembly areas, logistics stockpiles, staging points, and air defense assets. The goals of shaping fires are to
  - Isolate the current close fight,
  - Shape the next fight—set conditions for decisive operations,
  - Protect the force, and
  - Prepare the battlespace for decisive operations.
- *Counter strike* is used against opposing force weapon delivery platforms such as mobile missile launchers and long-range guns. It is also used to counter C^4ISR assets, particularly sensors and reconnaissance. The focus of counter strike is to attack the enemy preemptively before he fires by targeting the enemy's total strike system-weapons, sensors, and command and control.
- *Close support fires* are employed for decisive operations against (1) armor and infantry units in contact, (2) tactical command and control, (3) forward air defense, and (4) indirect fire assets such as cannons and mortars. The intent of close support fires is to
  - Attack enemy troops, weapons, and positions;
  - Fix the enemy and ensure freedom of maneuver for friendly forces; and
  - Fully synchronize the fires with the scheme of maneuver.

A major challenge for future operations is to create synergy between maneuver and precision fires. Maneuver is designed to achieve positional advantage over the enemy by positioning forces at decisive points to achieve surprise, psychological shock, physical momentum, and massed effects. Fires are used in combination with maneuver to place the enemy in a dilemma and a position of disadvantage.

- If the enemy remains in position, his forces may be isolated and destroyed by fires.
- If the enemy withdraws, attempts to establish new defensive positions, or maneuvers for counterattack, he may be exposed to effective use of fires.

Combining joint fires and maneuver requires a force to synchronize its capabilities in time, space, and purpose. The challenge is twofold: (1) to devise new concepts of operation (CONOPS) and tactics for faster, lighter dispersed forces to take advantage of abundant precision fires and (2) to determine if new effects can be achieved and whether new concepts can be enabled in maneuver.

From	⇨	To
Linked	⇨	Networked battle command
Access to joint system	⇨	Interdependent with joint systems
Connected to sensor outputs Less agile/heavy	⇨	Dynamic sensor to shooter linkages Strategic and tactical mobility
Lethal (through mass)	⇨	Lethal (through precision and volume)
Area effects with limited precision	⇨	Precise effects with area options
Large logistics burden	⇨	Reduced logistics requirement
Ability to mass fires	⇨	Ability to mass effects; lethal and non-lethal
24/7, all weather	⇨	24/7, all weather and all environments

Table 2-1: Indirect fire: future composition.

2.2 Indirect Fires on the Road to Baghdad

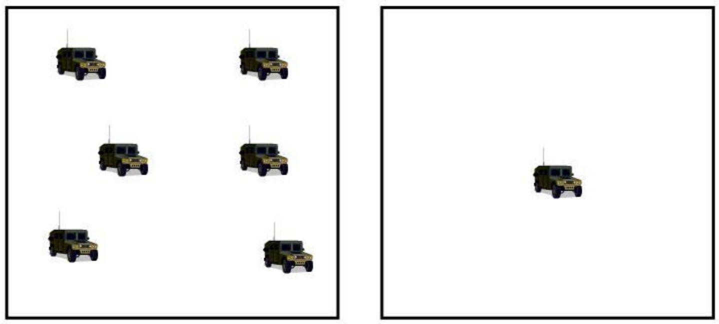
Over the course of its deliberations, the Task Force met with several members of U.S. Army and Marine Corps artillery battalions who participated in OIF. Their informal but remarkably consistent combat observations underscored well both the overall challenge of fire support on the modern battlefield and the need to integrate its elements more fully. The following list summarizes their observations generically:

- Most of the fires employed were massed fires with unguided munitions.
- These fires were judged to be quite effective in producing the desired results, although the efficiency of weapon utilization and overall integration was questionable.
- Most information on enemy force location came through direct contact with those enemy forces. Organic sensing assets were used extensively--primarily scout patrols and counter-mortar and counter-battery radars.
- Sensor information from sources beyond the organic assets was very limited. Products from imaging sensors, for example, were not generally available to the artillery units as they advanced toward Baghdad.
- Close air support was used more by the Marines than the Army. Its utility was limited by what several called an unreliable and overly complex process for requesting and coordinating fires.
- In many cases, the quality of target identification, collateral damage estimates, and bomb damage assessments was lacking.
- Training of the units did not match the scale of fires and pace of operations experienced in OIF.

The Task Force found many of these observations quite striking, and they informed much of the task's force's subsequent analysis.

2.3 Targeting Effectiveness Examples

Using the JMEM model, the panel ran some simple examples to examine the effectiveness of indirect fires against two different target sets. The first is an array of trucks (6) parked randomly in 300 x 100 m area. The desired effect is to “suppress” the unit from being able to carry out its normal functions. The second is a single truck that “must be damaged/destroyed.” The results using unguided unitary rounds are shown in Figure 2-1.



Target	Unarmored Truck	Unarmored Truck
Number	6 – 300 X 100m area	1
Munition	Unguided Unitary	Unguided Unitary
Aiming	Distributed Barrage	Distributed Barrage
TLE	25m	25m
Effect Required	Suppression (0.1)	Assured Destruction (0.8)
Rounds	18	868

Figure 2-1. JMEM-derived firing requirements using unguided unitary rounds.

The objective of suppressing the fighting capability of the array of trucks can be achieved with just 18 rounds, but to assure destruction of a single truck requires 868 rounds (according to the model). While the JMEM model is judged to be quite conservative, reducing the results by a factor of two leads to the same conclusion.

Figure 2-2 shows what happens when the TLE is reduced to zero.

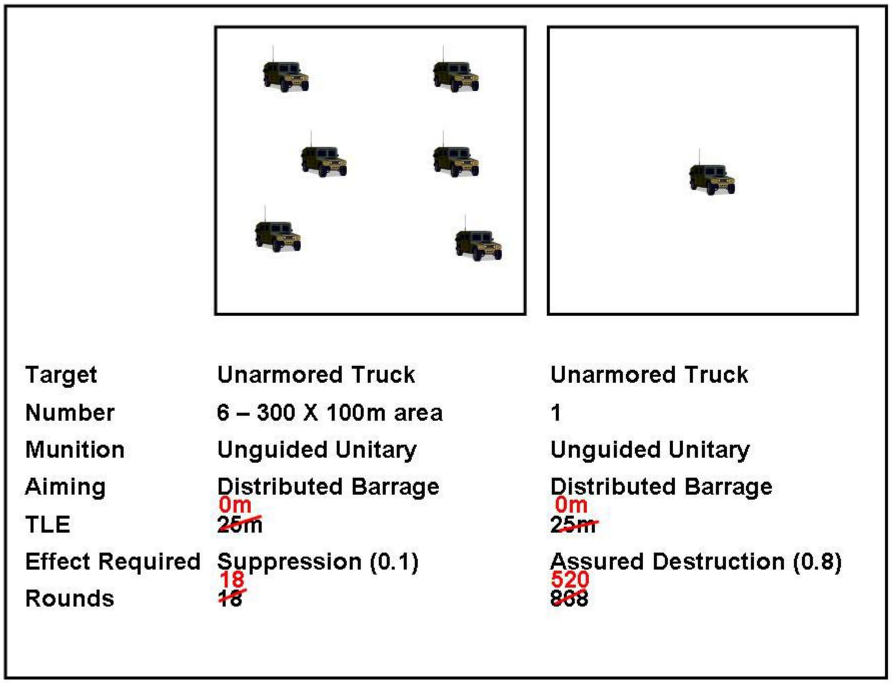


Figure 2-2. JMEM results with improved TLE.

The results for the array of trucks are unchanged. There is some improvement for the single target, but it still requires far too many rounds to be practical.

Finally, Figure 2-3 depicts the results of using observer adjusted fire, which eliminates the bias errors in the guns.

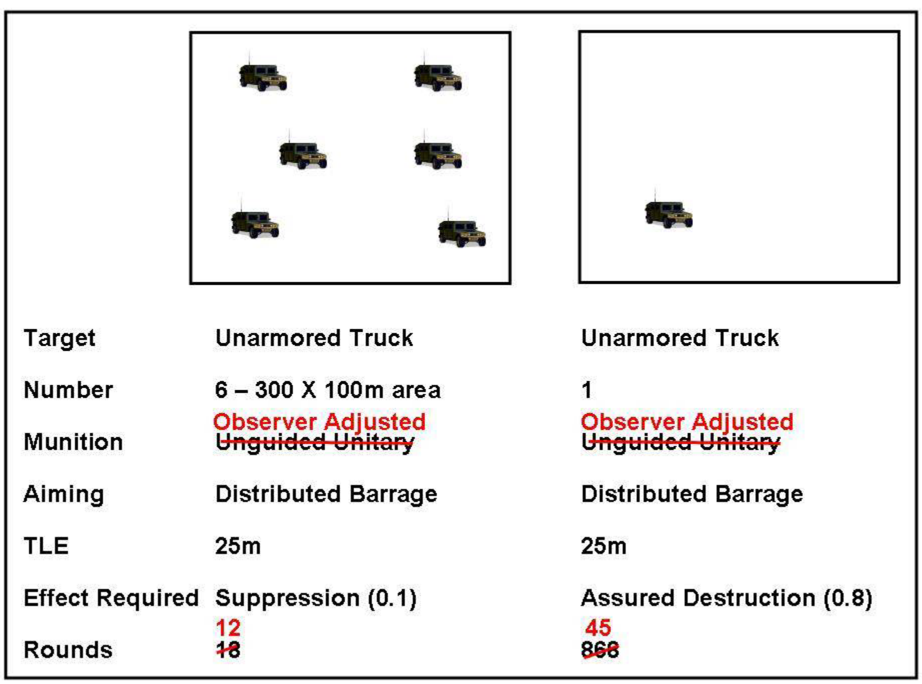


Figure 2-3. Observer adjusted files.

Observer adjustment obviously has a major impact in both cases.

The conclusions to be drawn from these (overly) simplistic examples are as follows:

1. Massed fires are effective for suppressing concentrated arrays of forces. The more targets in a given area, the better. Precise target location is not required.
2. Massed fires are inefficient and ineffective for high confidence destruction of a single target. To do so requires both precise target location and a precision attack mechanism.
3. Observer-adjusted fires make a huge difference in the effectiveness of current weapon systems.

When looking to the future, the critical question is this: "What target sets will we be facing and what effects will we be trying to achieve?" The answer is certainly "both of the cases presented here," but it is likely that we will be facing more of Case II than has been planned for in the past. The other obvious topic is observer adjustment. Is that the way to operate in the future, are the opportunities always there, or can that be supplemented or replaced with more technical precision approaches?

In general terms, Figure 2-4 suggests a future composition for indirect fires. This is a qualitative rather than a quantitative assessment.

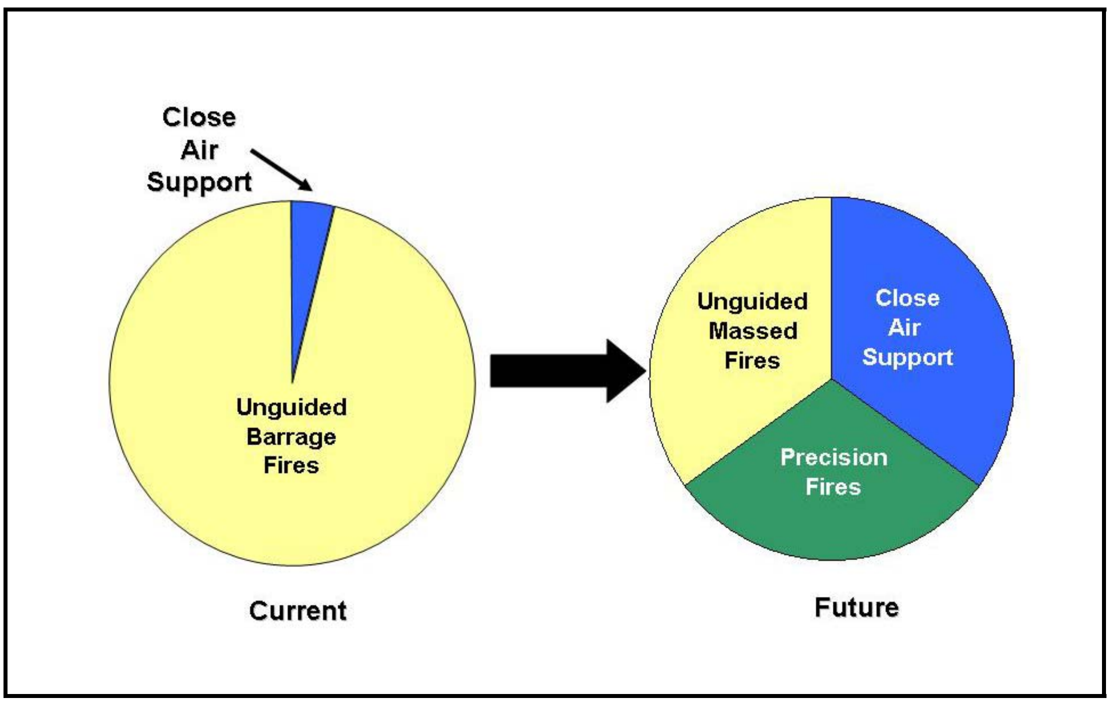


Figure 2-4. Indirect fire—future composition.

Today, the majority of indirect fires are unguided massed fires. In the future, we will still need massed fires for certain situations but also need to change procedures and weapons such that we can employ more air support and more accurate precision fires.

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3. FIRE SUPPORT WEAPONS

As defined for the purpose of this report, fire support weapons consist of various munitions and missiles used by the Army, Navy, Marines, and Air Force. This chapter focuses on those gun-launched munitions that are central to accomplishing the objectives of the Army and Marine ground forces. These weapons consist of a variety of systems, both operational and in development, which offer different sensor (INS/GPS, seeker), range (10 km to over 100 km), and lethality characteristics (high explosive to kinetic energy). Table 3-1 identifies the major classes of weapon investigated in this study.

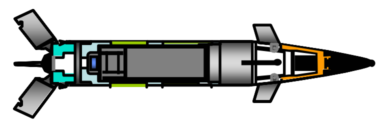
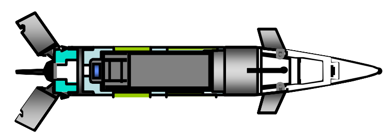
Class	Characteristics	Projectile
Unguided unitary	• Volume fires/effects • Distributed/ area targets • $500 unit production cost (UPC)	 e.g. 155mm
Guided unitary	• Pre-designated targets • Add INS/GPS & control • $15,000 UPC	 e.g. Extended Range Munition
Guided discriminatory	• Difficult targets • Add seeker & data link • $35,000 UPC	 e.g. Loitering Attack Munition

Table 3-1: Major classes of weapons investigated in study.

DoD has overcome many of the developmental challenges (navigation, control) involved in making these weapons a reality. These efforts should continue in other sensor and planning areas. How these weapons are employed, the benefits in terms of system effectiveness, operational utility, cost of ownership, and performance assessment will be detailed in the following paragraphs. Now is the time to step back and reevaluate how we effectively integrate the capabilities offered into the planning for future military engagements.[4]

3.1 Rules of Engagement and Weapons

ROE are usually established by the theater combatant commander (COCOM). They provide authorization for, and limitations on, the release of weapons by engaged forces. The

[4] While the material in this chapter focuses on the use of integrated fires from the standpoint of the ground soldier, the important contributions of the close air support (CAS) community in this area cannot be overlooked as part of the overall mission. However, the challenge of the CAS mission, and the precision weapons currently used in support of it, becomes one of a coordination issue handled as part of the joint integrated mission planning efforts. This material is discussed separately in chapter 5.

COCOM's authority comes from delegation of responsibility by the National Command Authority (NCA) for the management of all military actions in the COCOM's area of responsibility (AOR). This delegation of responsibility requires that the COCOM ensure that all military actions in his or her AOR are compatible with all relevant treaties and international agreements to which the United States is a signatory power. In addition, the COCOM must make every effort to assure that weapon release procedures are in place so that the possibility of fratricide, collateral damage, and civilian casualties are minimized, and that only targets of clear military value are attacked.

In recent conflicts, the ROE have become progressively more restrictive. The media can be relied upon to report instantly each and every perceived violation of the rules of warfare, the effects of inadvertent fratricide, civilian casualties, and extensive and unnecessary collateral damage. Thus the NCA places great pressure on the COCOM to assure that the occurrence of such undesirable events is minimized. The constraints of current and future ROE will be satisfied by

- Maximum use of coordinate seeking weapons with the minimum explosive yield compatible with target destruction;
- Improved blue-force tracking (BFT) systems;
- Minimal TLE;
- Reliable and precise target identification; and
- Rapid bomb damage assessment (BDA) capabilities.

ROE does and will continue to vary with circumstances within a theater. When the engaged enemy is an established military force in an open desert area where no civilians are present the use of unguided weapons (artillery shells and dumb bombs) will be permissible if the BFT system assures that the possibility of fratricide is vanishingly small. When combat is undertaken in urban areas, present and future ROE are likely to discourage the use of non-coordinate seeking weapons. In such circumstances the weapon of choice is likely to become the weapon with the smallest warhead compatible with target destruction. Small yield, precision weapons clearly minimize collateral damage.

TLE is one of the ultimate limitations on weapon delivery accuracy for any weapon that does not have its own means of determining precise target location. If a target's location cannot be specified with a level of precision that equates to the precision with which a coordinate seeking weapon can be delivered, weapon performance will degrade seriously. We may anticipate that in the future, when forces are engaged in an urban environment and the TLE exceeds some threshold value, the ROE will prohibit weapon release. Improved techniques for the reduction of TLE are urgently needed and are being developed by all Services.

For the foreseeable future, ROE will strongly prohibit weapon release in situations that may result in fratricide. In Operation Desert Storm, an estimated 24 percent of U.S. casualties resulted from "friendly fire." In OIF, the number of deaths from "friendly fire" was less than 3 percent. This favorable outcome resulted from a vastly improved BFT system that employed beacons, special panels, and interrogation systems. Again we may anticipate that when the location uncertainty of blue forces exceeds certain threshold levels, future ROE will limit the use of large warhead, non-coordinate seeking weapons in the areas of uncertainty. There is little likelihood that the ROE for future combat situa-

tions will be less restrictive with regard to possible fratricide.

3.2 Utility of Precision in Integrated Fires

Precision in integrated fires refers to the weapon approaching its intended target closely (i.e., a small total miss distance). This requires accuracy in both locating the target and guiding the weapon. The statistical measure of precision targeting and engagement is *total circular error probability* (TCEP), the radius of a circle encompassing 50 percent of the final distances between weapon and target.

Those with operational experience in land warfare consistently advise that fires need not—in fact cannot—always be conducted with precision. Situations arise in which, for example, the enemy's presence is only a possibility, moving forward quickly is essential, and prudence dictates a covering fire. A small TCEP has no operational benefit in such situations and firing unguided unitary (or "dumb") rounds in the general direction of concern is the appropriate course of action. In a wide range of other situations, however, (wider than has apparently been well understood previously) precision has an operational utility that outweighs its cost.

Precision's operational utility in integrated fires derives from a few interrelated benefits. First, use of fewer, smaller, and lighter weapons reduces total mass that must be brought to theater to kill a given target. Second, it increases launch platform equivalent effective magazine size. Third, smaller, more accurate weapons reduce the probability of collateral damage. Fourth, the ability to conduct the "one-shot/one-kill" mission increases the operational tempo. Finally, the accuracy and control of a precision weapons system design allows its delivery at significant stand-off range and permits effective lethality performance of these systems using smaller warheads.

Reducing total mass that must be brought into theater is critical to the force transformation DoD seeks. Reducing total mass will improve speed of response, reduce the cost of any given operation, and reduce the life-cycle cost of sustaining the force required for lift, logistics, etc.

Use of smaller, lighter weapons enables any given launch platform to carry more weapons, kill more targets, and stay on station longer. This endurance can be a key factor in enhancing operational tempo.

Reducing probability of collateral damage is another imperative in a world in which casualties of the uninvolved are broadcast to the world, exploited by the enemy, counterproductive to U.S. political objectives and become a political impediment to action. Attention to limiting collateral damage is so intense that it is often a pacing factor. Therefore, a capability to nullify targets with high confidence of doing no other harm can accelerate the tempo of operations. "One shot/one kill" is yet another aid to operational tempo; it increases the rate of killing targets and enables lighter, faster forces.

The extended range and control authority of precision weapons offers considerable advantage to the warfighter. The standoff range capability of these weapons will allow the soldier to reach targets up to 100 miles forward of the fire line. This capability is enabled by the ability to control the weapon in both flight to the target and in angle of fall (the angle at which the weapon hits the target) which increases the effect of the delivered warhead. Furthermore, in addition to the safety this offers the ground forces, it will

also improve the ability to conduct logistical re-supply activities by keeping the enemy force at significant stand-off distances.

In short, the advancement of precision weapons is making possible the ability to move from an environment of large, unguided, high-energy, short-range inaccurate weapons toward one of small, guided, minimal/kinetic-energy, long-range precision weapons that will provide the capability to hit the intended target with a single shot. Eventually this capability will not only minimize collateral damage but will also help to eliminate one of the leading causes of civilian injury and casualty: unexploded ordinance. Unexploded distributed submunitions are a leading cause of injury in the aftermath of a conflict due to their reliability performance. With precision weapons now a reality, it is time to reassess the usage of distributed submunitions as the primary explosive of choice in order to minimize and eventually eliminate the significant and unnecessary lethal collateral damage associated with the aftermath of their deployment.

3.3 TCEP: How Small is Small Enough?

How small does TCEP have to be to provide the above advantages? At what point does the cost of achieving a given TCEP outweigh its operational value? Answering these questions requires working the trade space between warhead size and TCEP, with the driving parameters being (1) the target type and (2) the warhead's lethality against the target type together with (3) the type and proximity of non-combatant elements that the ROE demand must be protected from damage. Answers are sought by designers of the materiel involved and by its users. Today, efforts of designers and users are frustrated by inadequacies of the JMEM, the only readily and universally accepted available source for how effective a given munition is at a given distance against a given target.

JMEM was developed for officers in the field to use in specific, defined operational conditions. It contains effectiveness information on specific munitions in the inventory against very specific target types; information derived from tests of these weapons over previous decades. Its format and content are not well suited for exploratory development and broad trade-offs. It lacks generalized data useful in designing a new weapon and is difficult to use in answering "what if" questions. JMEM's empirical foundation does not permit "physics-based" extrapolations. Furthermore, the tests on which its data is based were often for larger warheads and larger miss distances than are applicable for tomorrow's precision targeting and engagement systems. A revised or new form of JMEM is needed for these new purposes and new environment.

3.4 Dealing with the Total Cost of Ownership

The economic and military objective of a weapon system design should be to produce a weapon that neutralizes a wide variety of targets at minimum overall delivered cost. The overall cost of target neutralization is the product of the sum of unit weapon procurement cost, ownership costs, and transportation (delivery) costs times the number of weapons required to achieve the weapon's military objectives.

The four factors in the cost equation (*procurement*, *ownership*, *delivery*, and *numbers*) are generally difficult to estimate and are not inherently independent variables. Unit weapon procurement costs are rarely known with precision while a weapon is in the de-

velopment stage. Even when weapon programs have transitioned into production, unit weapon procurement costs are a strong function of the total number of weapons that are procured. The unit procurement cost of an individual shell, bomb, or missile varies significantly with the weapons warhead weight and designed WDE.

As an example, the conventional, unguided 155 mm artillery rounds have unit procurement costs on the order of $500. On the other hand, a round designed for the Navy's Extended Range Guided Munition (ERGM) will have approximately the same explosive yield as a 155mm round at an estimated unit procurement cost somewhere between $30,000 and $50,000 in quantity purchases. In other words, the ERGM round will offer increased range and greatly reduced WDE at 60 to 100 times the cost of conventional 155mm artillery shells.

Computing the number of weapons required to achieve a desired probability of target destruction is a complicated undertaking. It is a function that includes such factors as

- The explosive weight of the weapon warhead;
- The type of target (tank, bunker, truck, personnel carrier in defilade, etc.);
- The TLE;
- The angle of fall (AOF) of the weapon (re: control authority, which enables lethality);
- The staleness of meteorological data; and
- The WDE.

For a given target type and AOF (which in the case of artillery shells is related to the range at which a target is engaged), the number of artillery shells that must be delivered to achieve a 30 percent fractional damage (FD) most strongly depends on the TLE and the WDE. For example, JMEM calculations[5] for a single tank point target show that 347 unguided 155 mm artillery rounds will be required to achieve a 30 percent FD (when the AOF is 30 degrees and the TLE is 10 meters). Using a guided round with the same unitary warhead requires 10 rounds to achieve the same result. If a guided discriminatory round is used under the same scenario, only a single weapon is required to achieve the equivalent damage objective.

Although one may argue with the JMEM assumptions that lead to the requirements of such a large expenditure of unguided weapons, it is clear that significant economies of cost may often be achieved even when expensive precision weapons with low WDE are used. On the other hand there will be target sets and situations involving large TLE where using multiple, low-cost, unguided artillery shells is cheaper than using expensive weapons with small WDE. Little advantage is to be achieved when an extremely accurate weapon is used against a target whose location is very poorly known. The result of such an engagement is one where the weapon(s) *very precisely miss* the intended target.

Unit procurement costs generally increase as performance increases (measured in terms of decreasing WDE). For rounds designed to deal with stationary targets, the use of deeply integrated GPS/INS will provide a WDE that will generally be less than the TLE.

[5] See Appendix D for JMEM calculations.

The cost of such a round in large-scale production has been estimated to be somewhere between 20 and 40 times the cost of an unguided round. If rounds are to be designed to counter moving targets in adverse weather, the weapon will probably require the use of deeply integrated GPS/INS, a data link, and a seeker designed to see through or below the weather. This weapon will also be effective against any target in the absence of extremely precise TLE. Estimates made by knowledgeable personnel place the unit procurement cost of a weapon with such capabilities in the range of about 70 times the cost of an unguided artillery shell (i.e., about $35,000 per round). This figure represents the best estimate available at this time since there is no historical basis for this class of precision weapons. Although this multiplier represents a large increase in unit procurement cost, it also provides a capability that could not be achieved without the use of an inconceivably large expenditure of unguided artillery rounds.

Ownership costs of weapons in inventory are poorly documented and difficult to allocate on a per round basis. Significant costs are associated with maintaining weapons in inventory. The cost of ownership of weapons includes warehousing, guarding, testing, and batch re-certification costs. Most weapons have a finite shelf life so that even if they are not expended in combat (as many are not), they eventually have to be replaced. There is no uniformly accepted number that provides the true allocated cost of ownership of a weapon prior to its expenditure in combat. Many analysts estimate that the cost of weapon ownership equates to the initial unit weapon procurement cost.

Weapon transportation costs associated with the delivery of weapons from factory to the point of weapon release in combat are also difficult to document. These costs represent a significant fraction of the total weapon cost. Inquires with present and retired Transportation Command (TRANSCOM) officers failed to provide the panel with an agreed upon allocated cost of weapon delivery.

The largest factor in weapon delivery cost is the number of tons of weapons that need to be delivered. The delivery cost of a ton of precision-guided artillery rounds is the same as the delivery costs of a ton of unguided artillery rounds. The difference is that for precision-guided rounds, fewer tons must be shipped to theater.

The costs of weapons delivered in combat are difficult to assess. Separate organizations within DoD make weapon acquisition decisions, maintain them in inventory, transport them, deliver them within theater, and make decisions concerning their rate of employment. Cost tradeoffs between all elements above need to be worked, but no organizational home for such work currently exists.

3.5 Joint Munitions Effectiveness Manual (JMEM)

The preceding discussion on the various classes of weapons that can be applied to the integrated fire support mission highlights the need to determine which combination of the following factors offers the "best" option:

- Weapon selection
- Type of environment
- Level of probability of kill or fractional damage
- Type of target

In this context, "best" can be a very broad term but certainly encompasses such issues as number of weapons, degree of ISR support, minimum logistics, and least overall "cost-to-kill."

JMEM is a valuable tool in assessing some of the issues above. Fundamentally, it is a complex computer program that calculates the quantity of a given weapon that is required to achieve a given level of fractional damage against various types of targets as a function of TLE, staleness of meteorological data, aim point biases, firing doctrine, and the like. A highly experienced analysis community runs and maintains JMEM, and analysis results are documented in a large, multi-volume manual broken into classes of weapons (e.g., indirect fire, direct fire, air to ground, etc.). Historically, JMEM has been used to assess existing weapon effectiveness and to guide users in terms of operational firing doctrine and number of munitions required for the various weapon types these users employ.

Unfortunately, JMEM is not well matched to some of today's needs. It is not easy to use as an on-line tool to explore emerging weapons concepts because it requires too much specificity in terms of its many inputs. The documented manuals are oriented toward specific combinations of existing weapons and targets and are not well suited to performing parametric analyses. Because JMEM had its roots in the Cold War era, the entire JMEM culture has tended to focus on what it takes to halt or disrupt massed forces on the attack. "Fractional damage" and its related levels of a few tenths to "suppress" or "neutralize" stem from historical data on the performance of large troop concentrations suffering from personnel casualties or equipment losses. Today, although some conflict situations may entail the suppression or destruction of large forces, the more common situation is dealing with much lighter dispersed forces (perhaps even a few individuals) mixed in with non-combatants. The notion of neutralizing such groups with fractional damage on the order of a few tenths is not a realistic goal. Many of these groups are willing to sustain 100 percent casualties in the pursuit of their objectives and the potential possession of weapons of mass destruction makes an equipment survival rate of even a few tenths unacceptable.

Thus, the operational framework (as well as the toolset itself) needs to be improved. Building on the expertise that already exists, JMEM needs to be restructured to better support the performance of parametric analyses using a high degree of characterization of both weapons and target types. Users should be able to focus on high probability of catastrophic, functional, or mobility kill of individual target types. In addition, they should be able to specify confidence levels and easily delineate areas for specified levels of collateral damage. Such modifications (as well as JMEM analyst participation) would make JMEM an extremely valuable tool in supporting ongoing development activities, particularly in the early stages of concept exploration. It is also recommend that warfighter representatives become involved in the definition of JMEM improvements and modifications to ensure that the tool satisfies user needs as well.

3.6 Weapons Effectiveness

Despite the issues and limitations discussed above, JMEM proved to be very helpful in allowing the Task Force to assess the utility, effectiveness, and ultimately the cost-to-kill

of three classes of weapons: an unguided weapon with a unitary warhead, a GPS/INS guided weapon with a unitary warhead, and an guided discriminatory weapon.[6]

For the unguided unitary weapon, we also considered the case where a FO is used to adjust the target of the weapon. In discussions with the Army and Marines, we learned that most integrated fire support missions involving non-line-of-sight targets used an FO. In such circumstances, the firing source can "walk" the weapon into the target to remove weapon bias, thereby using fewer rounds than when firing in non-line-of-sight conditions without the FO benefit. Our analyses in the following paragraphs take the use of the FO into account when evaluating the effectiveness of the unguided unitary weapon. For precision weapons, the addition of advanced sensor technology is intended to obviate the need for the FO.

For these three classes of weapons, we determined how many rounds would be required to achieve a range of fractional damage. (We defined *damage* as a mobility kill). We treated TLE as a variable and characterized each weapon type by (1) its precision (the shot to shot random error in its ability to hit a given point) and (2) its mean point of impact (treated as a bias error over the entire distribution of fires). Table 3-2 provides these errors for the weapons considered. The results are representative of technologies that exist today.

Weapon	Precision in down range dimension (m)	Precision in cross range dimension (m)	MPI in down range dimension (m)	MPI in cross range dimension (m)
Unguided unitary	57	15	112	35
Unguided unitary (FO)	57	15	67	21
INS/GPS unitary	5	5	6	6
Guided discriminatory	1	0	0	0

Table 3-2: Assumed weapon delivery errors.

The results for a representative sample of the cases run are shown in the next two figures. (Figure 3-1 represents cases run for a soft target like a truck; Figure 3-2 represents cases run for a hard target like a tank). In each figure, a three dimensional plot is provided in which the base dimensions are TLE (ranging from 0 m to 30 m) and fractional damage of 0.1, 0.3, and 0.8. The bar height represents the number of rounds that must be fired to achieve the desired level of fractional damage at the given TLE. For the specific cases involving unguided unitary weapons, each bar has two levels – the lower being for the case of a forward observer and the higher for no FO. Held constant across the cases are the staleness of meteorological data (0.5 hours) and a weapon engagement range of two-thirds maximum range.

The trends in the two figures make intuitive sense. As target difficulty, required fractional damage, and/or TLE increase, the number of rounds required also increases.

[6] We specified an optical seeker-guided weapon (either semi-active laser-guided with a ground spotter or an imaging IR with aim point selection capability) with no warhead (i.e., a direct-hit, kinetic-kill weapon).

Conversely, increases in weapon sophistication, or, for the case of the unguided unitary weapon, through the employment of an FO, reduce the number of rounds required. What is not intuitive is the magnitude of these trends (note the log scale on quantities), particularly when a high degree of fractional damage is required. At a low fractional damage requirement against a soft target, the number of unguided unitary rounds that have to be fired seems reasonable. But at 0.8 fractional damage, the numbers exceed 1,000 (note that in all of the figures the bars are truncated at 1,000 rounds, since numbers in excess of 1,000 are operationally irrelevant). In contrast, the use of a FO can significantly reduce the number of unguided unitary rounds required. Furthermore, depending upon TLE, an INS/GPS guided weapon requires between one and two orders of magnitude fewer rounds than the unguided unitary weapon. And the seeker-guided, discriminatory kinetic-kill weapon requires only one round to achieve its objective, independent of TLE or fractional damage.

Against the hard tank target (Figure 3-2), the unguided unitary weapon requires an excessive number of rounds in all cases, even when an FO is available. The INS/GPS-guided unitary weapon appears to be useful at low combinations of TLE and fractional damage but require excessive numbers of rounds elsewhere. And similar to the soft target case, the seeker-guided discriminatory weapon remains a "one round to kill" weapon.

All of the cases represented in Figures 3-1 and 3-2 entailed the engagement of an isolated single target. We also analyzed the same cases for "area" targets, i.e., a group of six trucks or tanks spread out over a small area. The results are provided in Appendix D but yield the same trends and conclusions as the single target cases discussed here. Also provided in Appendix D are the results against a medium hard target such as an armored personnel carrier. The results for it are quite similar to those for the tank above.

The obvious question that remains is whether the increased unit cost for the more complex INS/GPS guided unitary and/or seeker guided discriminatory weapons are offset by the decreased numbers of rounds required. The following section attempts to answer that question.

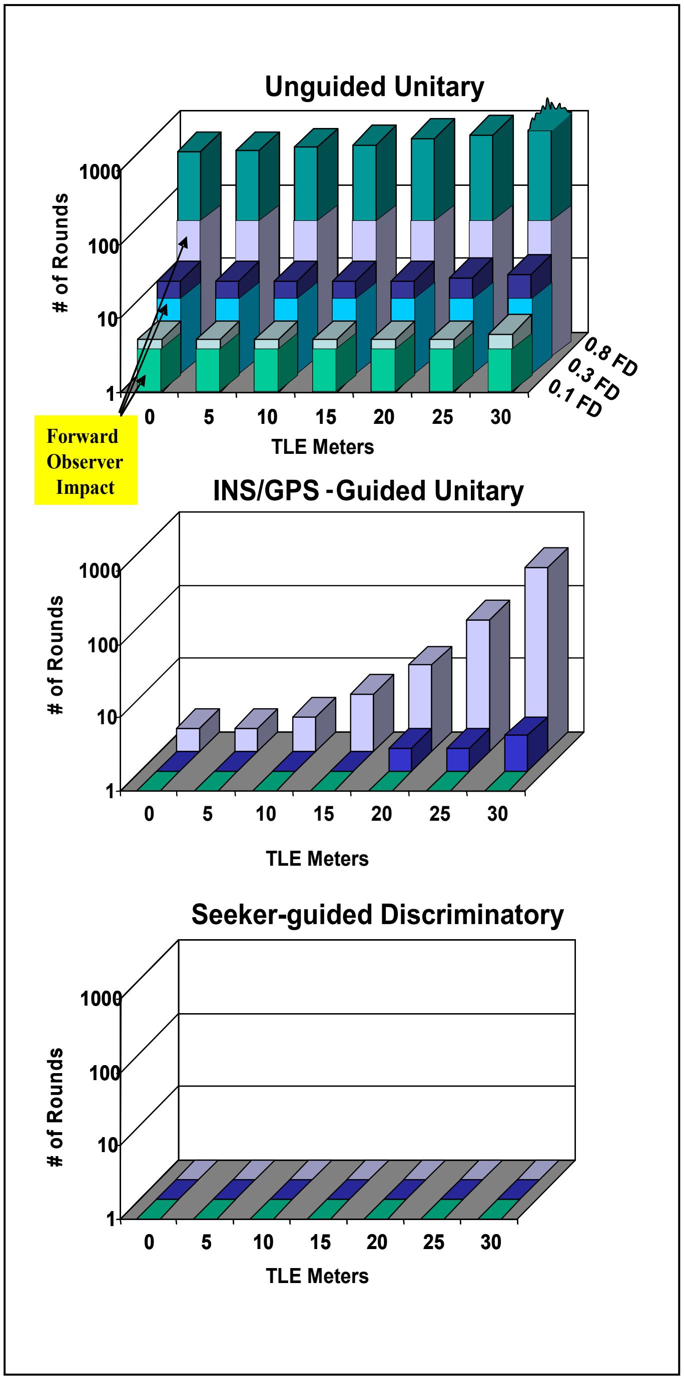


Figure 3-1: Soft target, truck.

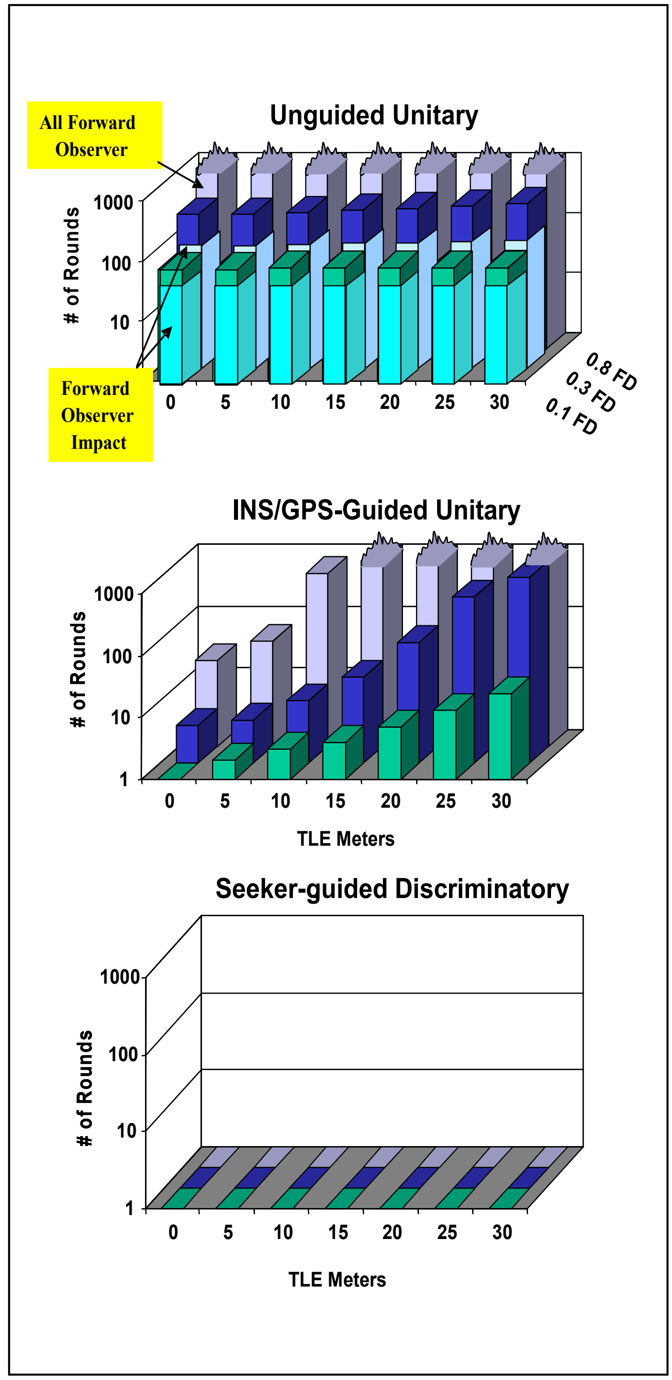


Figure 3-2: Hard target, tank.

3.7 Total Cost-to-Kill

In order to answer the question of whether the increased cost of weapon complexity is offset by the reduction in numbers of weapons required, the total cost to kill a target to a desired fractional damage level has to be determined for each of the weapon options. *Total cost* should consider unit procurement cost (UPC), the cost of getting the required weapon to theater, and the necessary support cost. For the UPC of the unguided unitary weapon, the Task Force used current figures for weapons of this class (about $500 a round). The one element of the unguided unitary weapon cost not included was the cost of training, fielding, and putting the forward observer on station to provide the firing solution updates during the IFS mission. This cost, which would be eliminated with the use of precision weapons, does not significantly alter the findings in this report. However, it remains one of the many "elusive" total cost of ownership variables that we believe a good DoD systems engineering capability would provide.

For the INS/GPS-guided unitary weapon, the Task Force considered the cost of adding the INS/GPS guidance and the cost of providing the necessary aerodynamic control to divert the weapon to its guided aim point. Using projected figures for guidance systems of this type and considering the cost of existing weapons of this type, we determined a UPC figure of about $15,000. For the seeker-guided discriminatory weapon, the panel drew upon a two-year-old Defense Advanced Research Project Agency (DARPA) study on inexpensive seekers. In that study, a body-fixed imaging IR seeker was projected to cost in the range of $10,000 to $20,000 per round. Using a mid-point figure of $15,000 for the seeker and associated electronics and $5,000 for a data link (another DARPA study projected the cost of a similar data link at $2,000), we added $20,000 to the INS/GPS-guided unitary weapon for the seeker and data link. This resulted in a projected UPC of $35,000 per round.

To get a handle on shipping and support costs, we assumed crated rounds with a loaded crate weight of 300 lbs. We also specified crate dimensions. A commercial carrier provided a bid on shipping 1,000 rounds by sea from Houston, Texas, to Jeddah, Saudi Arabia. The carrier proposed employing three barges, each carrying one-third of the total quantity at one barge per month (anytime the vessel was available to Jeddah). The total cost per barge was $165,000, or $495 per round.

We further assumed that the rounds would be stored in-theater in a warehouse-like structure. Allowing space for the crates (stacked four high) as well as aisle, access, and administration space, yielded a total requirement of slightly over 20,000 sq. ft. At $2 per square foot per year, this came out to be $40,000 for warehouse space. The cost of providing two guards on a 24/7 basis at an enlisted soldier cost of $25,000 per year yielded another $150,000 (depending on how shifts and 7 day coverage worked out). Given the $40,000 for warehousing and the $150,000 for security, the total storage cost was $190,000, or $190 per round. Adding this $190 per round for storage for one year and the $495 per round for shipping, we rounded the total up to $750 per round to account for any other factors not considered. We assumed that any conflict involving these weapons would not last more than one year.

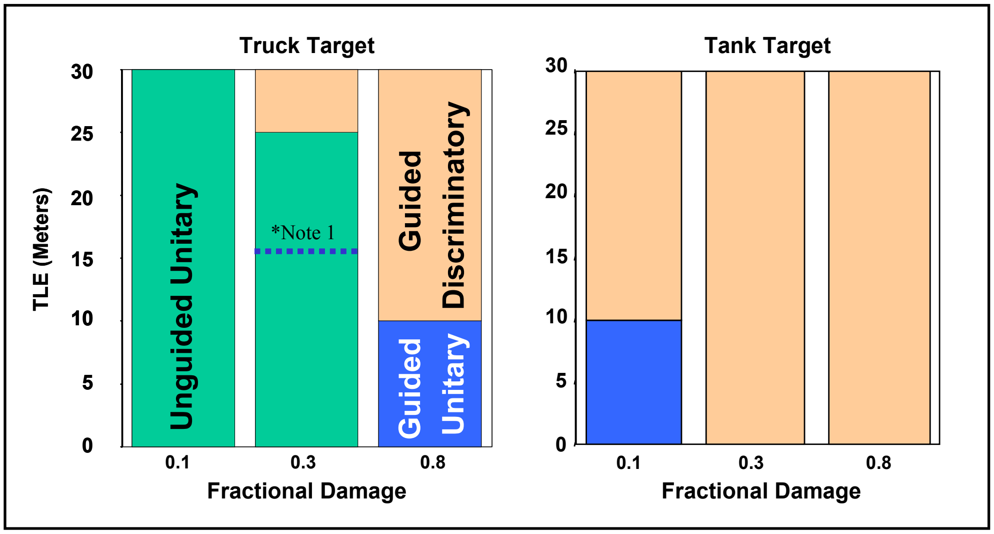


Figure 3-3: Truck target; least cost-to-kill weapon option

Figure 3-4: Tank target; least cost-to-kill weapon option

All unguided unitary data in above figures assumes the use of a forward observer.

**Note 1: For Truck target, 0.3 FD and from 0m – 15m TLE the Guided Unitary option is the least cost when Forward Observer not available.*

Once we established the three UPC figures and the $750 per round support cost, it was a simple matter to calculate the total cost-to-kill for the three weapon types as *the number of weapons required* (from the JMEM results) multiplied by *the sum of the UPC and support costs*. Using these total cost-to-kill figures, we determined the least-cost weapon option for the various combinations of fractional damage, TLE, and target type. Figure 3-3 maps the results for the soft target, Figure 3-4 for the tank target. For example, against the truck target at a 0.1 level of fractional damage, the unguided unitary weapon was the least expensive option, independent of TLE within the range of 0 to 30 m. For the same target but at a fractional damage level of 0.8, the unguided unitary weapon was never the least expensive option. Rather, at a TLE of 10 m or less, the guided unitary weapon offered the least cost-to-kill and above that TLE the seeker-guided discriminatory weapon offered the least-cost approach. Some general observations are apparent:

- In a situation in which the objective is low-level attrition (e.g., 0.1 FD) of soft targets (trucks, dispersed troops, etc.), the cost spent on precision has no financial payoff and the least UPC unitary weapon offers the least total cost to achieve the desired effect.
- In contrast, in a situation in which the objective is a relatively certain level of kill (e.g., 0.8 FD) of hard targets (tanks, APCs, etc.), precision weapons—even at a UPC of nearly 70 times that of the unguided weapon—offer the least total cost-to-kill.
- In between these two extremes in target difficulty and kill expectation or fractional damage, a "half-priced" INS/GPS guided unitary weapon (no seeker) plays

an economically useful role. That said, an even stronger rationale for the INS/GPS guidance technology is to act as a critical enabler to make inexpensive seeker-guided weapons a reality.

In our cost analyses of these options, we examined the cost "crossover" points for the various weapons. We found that variations in UPC and support costs of 50 percent (and in some cases even 100 percent) had little effect on the maps above; when the number of weapons required to achieve a given fractional damage level starts to rise, it rises rapidly. This makes the transition point from a less to a more sophisticated weapon a sharp one that is not overly sensitive to even moderate UPC or support cost variations. Appendix E contains the detailed cost data underlying the maps above.

3.8 Balancing WDE and TLE

How total miss distance total circular error probability (TCEP) depends on WDE and TLE is a function of the weapon guidance scheme and the weapon employment concept. For weapons with seekers, the seeker must be designed to accommodate the TLE. Viewed in the context of a system-of-systems design, this involves balancing the seeker's capabilities with those of the target location system (and possibly the weapon's communication system). As we will discuss in Chapter 4, TLE should be no more than several tens of meters to keep seeker cost commensurate with weapon cost. For weapons with seekers, however, TCEP is normally semi-independent of TLE and depends on (1) the seeker's ability to acquire the intended target (a weaker function of TLE) and (2) the weapon's homing capabilities.

If the weapon has no seeker and is employed against targets "one-on-one," then WDE and TLE need to be in balance. This simple formula applies:

TCEP = SQRT (WDE**2 + TLE**2)

With TLE fixed, TCEP decreases significantly as WDE is reduced until WDE is about half the value of TLE (the point of diminishing returns). Similarly, we can reverse the roles of TLE and WDE in this statement.

If the weapon has no seeker and is employed against targets "many-on-one," then reducing WDE can provide benefit even when WDE is much smaller than TLE. "Many-on-one" employment concepts are useful when the target is distributed (e.g., troops spread over a wide area) or when TLE is very large. Precision in WDE enables operational commanders to fire weapons in a pattern and efficiently cover a wide area. In this case, the point of diminishing returns in reducing WDE is reached when WDE (expressed as circular error probable (CEP)) is about half the warhead effectiveness radius.

As the above discussion suggests, TCEP is a total system concern. What warfighters need is a suite of systems for integrated fires flexible enough for a spectrum of operational situations, providing in each situation an appropriately balanced weapon and targeting system. Warfighters do not have this today, and neither DoD's acquisition system nor the warfighters' operational planning systems are geared to provide it to them in the future.

What exists today in the acquisition system is a set of stovepipes, each setting requirements for, developing, and fielding some element of the integrated fires system. Weapons and targeting systems are procured independently. There is too little attention to

targeting systems compared to that for weapons but, more to the point of the discussion at hand, no overarching system engineering exists. In the Task Force's view this overarching system engineering and development oversight needs to be created.

Operational planning systems also need to give war fighters the ability to explore "what if" questions, to examine implications of combining different available systems together, and to try out (via modeling and simulation) new concepts of operation. While first steps have been taken in this direction (e.g., JMEM is integrated into AFATDS), the full power of modern information technology has not been brought to bear on this problem.

3.9 Weapon Design Issues

GPS accuracy and anti-jam navigation

One of the pressing challenges for precision guided gun-launched munitions has been that of affordable guidance technology. This has long hampered making precision weapons a reality for the warfighter. Recent advances in micro-electro-mechanical (MEMS) technology has solved this challenge and removed one of the major obstacles for this class of weapons.

The advantages of MEMS inertial measurement units (IMUs) are smaller packaging designs, lower cost per unit verses other IMU technologies, and environmentally robust system designs. MEMS IMUs currently being pursued by the Army will provide units on the order of 2 cubic inches in size available at cost estimates of $1,200 per unit in expected quantities. These units will also deliver performance at approximately one degree per hour, which is more than sufficient to meet the system needs of today's precision weapon designs. Finally, an added benefit of MEMS silicon solid-state designs is that these instruments eliminate the mechanical or electro-optical components that are environmentally sensitive to conditions that experience up to more than 12,000 Gs.

The affordability of these military MEMS designs is made possible by the leverage provided by the commercial markets which utilize the same manufacturing processes and equipment. Commercially available MEMS inertial instruments typically perform in the hundreds of degree per hour range and are used in air bag and anti-skid systems for automotive designs and in game and photography applications. These markets have helped drive a larger commercial market demand for such MEMS instruments and permit the military to enjoy the economies of scale provided by these larger markets.

The key to being able to use commercial-quality MEMS inertial technology in precision weapons applications is a systems design that includes GPS technology. This combination of MEMS inertial navigation with GPS navigation provides a system capability that meets precision weapon delivery requirements. The INS/GPS systems also needs to include jam resistant (anti-jam or AJ) techniques such as GPS Deep Integration, antenna switching, or other advanced signal processing techniques that will improve the AJ performance to meet military requirements in this area.

The Navy/Marine Corps and Army have used these MEMS-based guidance systems to develop innovative projectiles demonstrate (1) weapon ranges of over 50 nm and (2) improved weapon lethality through the delivery of explosive energy at the proper geometries, or angle of fall, to maximize warhead effectiveness. Finally, when combined with data-link and seeker technologies, these MEMS-based INS/GPS systems can pro-

vide midcourse corrections and terminal abort capabilities necessary for neutralizing fixed and moving targets while at the same time minimizing the chances of collateral damage and fratricide.

The system tradeoff to be made for INS/GPS sensor performance is demonstrated in figure 3-5. Three classes of IMUs are represented in the graph:

- 100 degree/hour,
- 1 degree/hour, and
- .01 degrees/hour.

The figure helps identify where to place the technology emphasis when considering system demands for anti-jam.

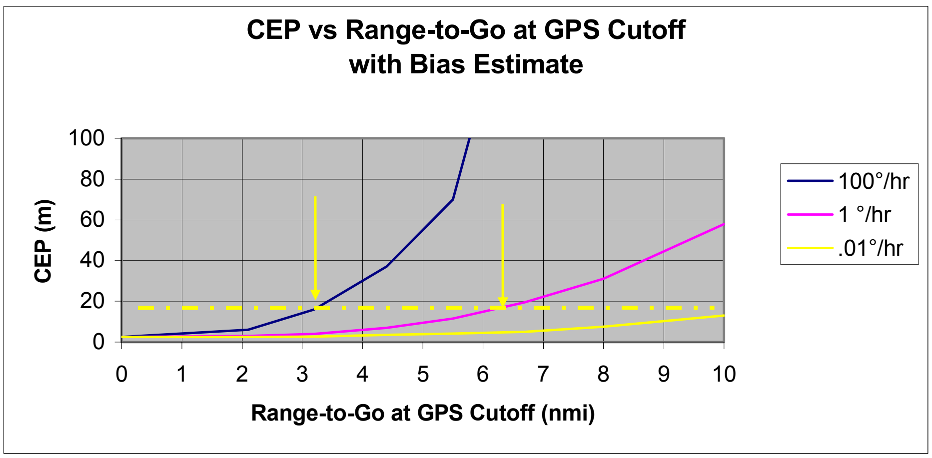


Figure 3-5: IMU requirements driven by GPS jamming scenarios.

The figure shows that in order to deliver a 20 m CEP and provide for anti-jam expectations, one can invest in inertial or GPS technologies. Given a fixed level of anti-jam in the INS/GPS system, one would need to invest in a higher quality IMU (better instrument performance) depending on how far from the target GPS might be lost. Conversely, given a fixed IMU quality, one could alternatively invest in more robust GPS (re: anti jam) depending when GPS is expected to be lost. The trade-off between more inertial or more AJ has to be determined at the system application level.

DoD has mandated that the GPS Selected Availability Anti-Spoofing Module (SAASM) be a component of all military weapon system designs. It appears that this mandate unnecessarily burdens certain systems developments, particularly those found in the integrated fire support (IFS) area. It is the opinion of this Task Force that certain military missions such as IFS can meet their anti-jam (AJ) requirements without the SAASM component, which offers questionable mission benefit. In fact, SAASM adds needlessly to power, size, weight, and cost challenges involved in system design for these missions. While SAASM may offer other missions (e.g., missions involving aircraft or missiles) the benefits of signal authentication or over the air re-key, these are not required for integrated fire support weapons. We recommend that AT&L reevaluate its mandate for

SAASM in all military system designs and consider other alternatives for AJ performance that are available without over-specifying system requirements.

Now that the Services have solved the integrated INS/GPS problem, they should undertake the challenge of developing a guided integrated fuse (GIF). This development would provide the potential of converting millions of existing unguided "dumb" projectiles into "smart" weapons. The GIF concept creates a "smart" NATO standard fuse replacement that users could easily retrofit onto existing munitions and mortars already in the inventory. This "smart" replacement would provide the guidance, navigation and control (hardware and software components including the canard surfaces for steering the projectile) capabilities to enable near-precision kill within the same physical volume constraints of the existing standard "dumb" fuse.. Such a concept would permit field conversion of existing dumb weapons into short-range precision weapons, thereby offering additional logistical and training savings. While the range and CEP estimates for such converted weapons are estimated to be less than those for the precision weapons discussed earlier in this report, a GIF-equipped weapon would provide an affordable and complimentary capability to the suite of precision weapons. A GIF replacement fuse would add an estimated $2,000 to the cost of the existing unguided unitary round, yielding a converted projectile UPC of approximately $2,500 (using the original estimate of $500 for an unguided projectile). NAVSEA/Dahlgren efforts in this area have shown promise in early exploratory tests. These efforts should continue.

AT&L should be recognized for efforts in addressing the affordable INS/GPS challenge. Through the Common Guidance Inertial Measurement Unit (CGIMU) Program, it has exerted the proper technology pull from the science and technology (S&T) community that will make affordable precision weapon guidance a reality. The program will deliver an INS/GPS system package (3 cubic inches) that addresses the AJ trades mentioned above. An important point to note here is that both its size and performance will enable the use of these same systems in other military (personal navigation, autonomous systems, etc.) and commercial applications. These additional applications will further expand market quantities and allow the military to continue to enjoy the affordability offered by large-scale production. AT&L needs to demonstrate the same leadership in data-link and seeker technologies to make the entire precision weapon objective complete.

Low-cost seekers and data links

The previous sections have highlighted the benefits of precision. In benign environments and against fixed targets, precision weapon delivery error in the order of 5 m can be obtained with inexpensive guidance utilizing GPS-aided targeting and navigation and good precision inertial instruments. If GPS is denied because of electronic countermeasures (ECM) or if the target to be attacked is not fixed, then guidance based on a GPS target location at the time the attacking weapon is launched or fired will not yield precision. Under these conditions, something else is required to maintain the 5 m precision. And under any conditions, if weapon delivery of significantly less than 5 m is desired—as in the case of kinetic weapons (i.e., weapons that have no warhead and depend upon achieving a "hit" to be lethal)—something more than GPS/INS alone is required.

Seekers and data links provide the added functionality needed to maintain precision against moving targets, to mitigate the effects of compromised GPS accuracy, or to

achieve very small WDE (in the 1 m or so class). Data links alone can achieve this under certain conditions if precise external data is available to the accuracy required. One example of this was demonstrated in the DARPA Affordable Moving Surface Target Engagement (AMSTE) program, in which good range data from two off-board radars was provided to a weapon through a data link, allowing the weapon to construct and maintain a moving target's precise location and to guide to a precise intercept. Such a technique, however, depends upon two or more airborne radars with precision in at least one dimension being available to maintain visibility and track on the target through a relatively wide bilateral angle. This may be difficult to achieve in some geographic situations or because of the scarcity of multiple persistent ISR or tracking assets

The more general solution (in addition to the data link) is to place on the weapon a seeker which can track the relative target position to intercept. As the weapon closes on the target, the accuracy of the seeker grows and sub-meter accuracy is possible at intercept. The obvious drawback of such a solution is the cost of the seeker. If such a technique is to be feasible and practical, the seeker cost must be kept low.

The key to keeping the seeker cost low is to ask it to do as little as possible. To achieve this, the whole weapon system must be architected to limit the required seeker functionality. Moving parts in a weapon always cost money, particularly if their absolute position must be known with great precision at all times. However, if the required field of view of the seeker is relatively small during the entire time it is employed, then no need exists to move anything; the seeker can be fixed and precisely aligned with the body axis of the weapon during manufacture.

The least expensive type of seeker is one employing passive optics. Laser Detection and Ranging (LADAR) is moderately more expensive and radar or radio frequency (RF)—which, at certain frequencies provides the only true all weather modality—is significantly more expensive. If, however, the concept of operations for the seeker is to use it only in the very terminal part of the engagement, then it can approach "all weather" capability using optics by operating only at altitudes below which it is rarely cloudy. Ninety-five percent cloud ceilings in difficult weather areas such as Korea typically lie between 0.3 and 0.5 km in altitude. In more benign weather visibility areas, cloud ceilings are most often above 0.5 to 1.0 km.

If passive optics are going to be used and day/night operation is required, then infrared (IR) is the spectral choice. To satisfy the requirement to "see" the target under restrictive ROE, one would want to employ an imaging IR capability. But to keep it inexpensive, it is preferable not to cool it to cryogenic temperatures, which is a significant added expense. Fortunately, uncooled optics are consistent with operating only below 0.5 km altitude or so, because typical dive angles of 30 to 45 degrees and above yield short acquisition ranges of 1 km or less, which—again—is consistent with the use of uncooled optics. Lastly, processing is expensive, so any "heroic" signal processing such as is required with broad area automatic target identification/target recognition should be avoided.

The obvious question at this point is how to architect the weapon system in such a way that the seeker does a useful job if it only operates (1) at very low altitude; (2) at very short range; (3) without having to look for targets over a wide field of view; and (4) without requiring any kind of sophisticated automatic target recognition, even under restrictive ROE. The answer lies in the guidance ability provided by today's GPS/INS

strictive ROE. The answer lies in the guidance ability provided by today's GPS/INS navigation.

Against a fixed target, today's INS/GPS guidance can direct a weapon to within a 5–7 m CEP of the target. Even with GPS denied for the terminal portion of the weapon's flight, a 15 m CEP is achievable. Against a relatively fast moving ground target, the incorporation of a data link with as much as 300–500 m/s latency to update target position can maintain a 15 m CEP. This means that a high-probability seeker basket of about ± 50 – 60 m can be established for the weapon.

If the weapon is diving at 60° and the cloud ceiling is at 500 m, the required acquisition range of the seeker is about 600 m. This is consistent with low-sensitivity optics. The required field of view is also relatively small: about 10 degrees at acquisition. The driving requirement on the size of the focal plane array (FPA) is to have 300 pixels on target shortly after acquisition to confirm target ID and, if scanning optics are to be avoided, to cover the required acquisition field of view within the constraints of a reasonably sized focal plane. This all works out to an FPA of between 256 x 256 and 512 x 512. Lastly, a "divert" of the weapon during the time after seeker acquisition is required to home out the INS/GPS delivery error. With typical weapon kinematics of about 250 meters per second (m/s) velocity and 3 Gs of divert capability, the 50–60 m delivery error can be covered. All of this is self-consistent; enabled by today's GPS/INS capability; and, at reasonable production rates, consistent with a seeker cost on the order of $10,000 to $20,000.

The addition of a suitable low-cost data link with a cost on the order of $5,000 (a recent DARPA program—Banshee—had a bogey cost of $2,000) brings the total of the incremental electronics guidance package to between $15,000 and $25,000. As was the case with the seeker, the key to the low-cost data link is restricting its functionality to the minimum required and making it self-adaptable to a wide range of existing platform data links. Link bandwidth can be relatively small—a few kilobit (kb) to about 100 kb depending upon whether a final seeker "snapshot" of the target is to be sent back to the targeting network just prior to impact (for BDA purposes). The design philosophy of the electronics also has to be geared to low cost, exploiting the fact that the total operational lifetime of the data link is seconds, not months or years. Component cooling, battery life, derating factors—all can operate much closer to failure limits than conventional electronics, minimizing what is required for a few seconds of reliable operation. If realized, low functionality, an "expendable" design philosophy, and broad applicability to existing network protocols and interface requirements will guarantee low cost, both in acquisition and in terms of platform installation.

The technology for creating such a data link exists today, and in effect, can come about by combining the two technologies of (1) today's mobile ad-hoc networks and (2) real-time control. A few years ago, DARPA initiated Banshee (a pilot program built on the objectives described above), but no follow-up is evident today. In the interim, the U.S. Air Force seems to have become more supportive and aggressive on the subject of weapon data links. While this is commendable, the Air Force has not focused on universality and extremely low cost to the same degree as the earlier DARPA initiative.

Even if achievable, a cost of $15,000 to $25,000 for a seeker and data link is not likely to be affordable as an upgrade to field artillery rounds, even though the JMEM data indicates a potential saving of hundreds of rounds per target. But where true, highly con-

fident, swift surgical kill is required, the low-cost seeker/data link combination on a small missile (as is being developed in NETFIRES for Future Combat Systems (FCS) or for a specialized guided projectile should be pursued with the same vigor and seriousness as INS/GPS was a decade ago. For a cost of about $20,000 a lethal kill can be delivered to a fixed or moving hard target in ECM or bad weather with one round utilizing off-board ISR assets without imposing heroic demands, either in quality of information or number of assets. And as we explain below, the low-cost seeker also can provide significant help in achieving the identification required under restrictive ROE and in fulfilling the elusive BDA that Army and Marine Corps combatants argue they need to achieve efficient fires.

Identification (ID) and weapon design

The imposition of restrictive ROE in recent conflicts has placed a greater degree of emphasis on obtaining very reliable target ID prior to prosecuting an attack on a target. This has always been a difficult task, and in an "eyes on target" environment requires either a forward spotter close to the target area to confirm ID or the presence of sophisticated, high-resolution ISR assets.

In the previous section, a case was made for pursuing the development of inexpensive seekers and data links for guided projectiles and ground battle element strike missiles to enhance precision, low collateral damage strike capability, or more specifically, to obtain lower total CEP under a wide variety of conditions. It was envisioned that these seekers and data links would be employed as follows:

1. After identifying the target from an ISR or C^2 asset, launch or fire the round with a stored IR "picture" of the intended target.
2. Guide it in midcourse using its own inertial instruments and GPS data to a seeker "basket" under cloud cover.
3. Acquire the target with the weapon's imaging IR seeker over a narrow field of view.
4. Correlate the image (which should cover a few hundred pixels of the seeker focal plane) with the image stored at launch, correcting for the geometry of the attack.
5. Terminally guide the weapon to the target (or any point on the target) using the continual stream of imagery obtained through the seeker as the weapon closes.

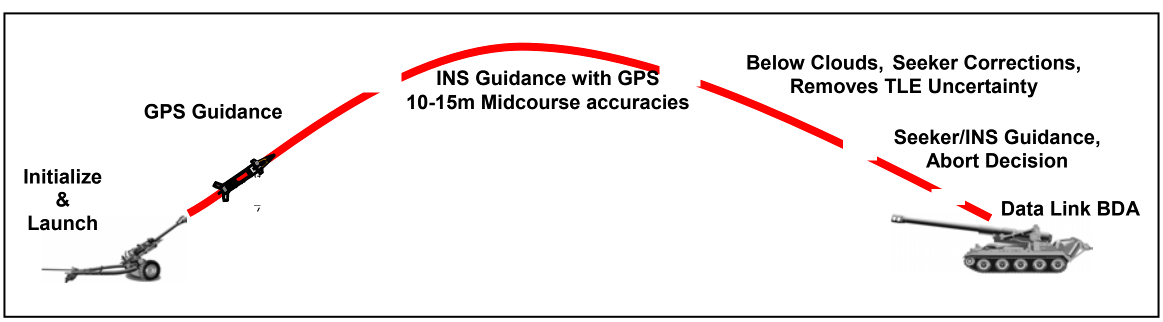


Figure 3-6: Combat Identification Scenario.

At one second before impact, the quality of the imagery will have improved to the point that between 1,500 and 3,000 pixels of target information will be available. This "medium quality" image could be used, if desired, to provide a final confirmation that the target under attack was the same as the one originally intended. A more stringent threshold could be established than at launch, based upon the increased number of pixels on target, and if this threshold was not exceeded, the engagement could be aborted or "called off." At one second to impact, the weapon could be diverted by up to 50 feet, which would render the target relatively safe for a weapon that depended upon a kinetic impact for a kill or one that contained a small warhead (e.g., only a few pounds of high explosive). At the time the abort decision was made onboard the weapon, an appropriate message would be sent back through the data link to the launch or control platform.

Although no time would exist for true human interaction in this process, it would provide an extra layer of confidence that the target that had been identified prior to the decision to attack remained the same target that was actually being attacked just prior to impact. The Task Force believes that using the weapon's "eyes" for this purpose, particularly as the demands for ID surety increase, has merit and should be explored as part of the ongoing weapon development process and the search for effective BDA solutions.

Battle damage assessment (BDA) and weapon design

BDA is the after-action assessment of the degree to which a target has been disabled. Total destruction, functional disablement, the inability to move, and a host of other outcomes are all possible results of an attack on a given target and are critical inputs into a ground commander's decision as to what to do next. Unfortunately, the Task Force repeatedly heard from units that had been operational in Operation Enduring Freedom that they had not been served well by the BDA function. Their requests to higher echelons for BDA support often went unanswered or at best took an unreasonably long time to get serviced.

Lacking a responsive and accurate BDA, the ground commander has only three options:

1. Assume the target has been neutralized to the desired degree and move on, *which if wrong needlessly increases the risk to the forces under his command.*
2. Assume the target has not been neutralized to the desired degree and strike again, *which if wrong needlessly wastes fires resources, extends the logistics tail, and slows the pace of battle.*
3. Wait an additional amount of time until accurate BDA is available from external sources, *which needlessly slows the pace of battle and reduces operational tempo and hampers synchronization of the total effort.*

As in the case of the ID function discussed previously, reliable BDA requires eyes on target. Given that (1) time is critical, (2) ground units may not be in the immediate vicinity of the target, and (3) higher echelon ISR assets are often over tasked (causing them to serve the battle element BDA function slowly, if at all), an organic ISR function for BDA purposes could possibly be created or enhanced at the organic level. But as seen in the previous two sections, many modern organic battle element weapons may soon have "eyes" in the form of imaging seekers. This raises the question of whether those same eyes could be exploited for the purposes of organic BDA. The Task Force believes that

the potential is inherent in these new weapons to provide useful supporting information to the BDA function and that USD(AT&L) should explore this function.

At about one aerodynamic time constant before impact, any guided weapon has on-board knowledge of how close to the *intended* target point it will hit. There is not sufficient time left in the flight of the weapon to do anything with this knowledge to reduce miss, but that knowledge exists if needed for other purposes. The knowledge of where on (or off) the intended aim point a weapon will hit could provide a measure of predictive BDA, except for one critical consideration: lacking its own eyes, the weapon doesn't know (nor, in fact, do the shooter or the targeting asset) the specific TLE for a given shot; only the statistics are known. In the case of modern weapons with seekers, however, TLE is irrelevant once the seeker locks on to the target. In this case, everything that is required to predict where the weapon will impact relative to the real target is known on-board the weapon and could be provided to the shooter or the C^2 network via the weapon data link. This kind of "*predictive BDA*" could serve a very useful function and not add any significant requirements to the weapon system electronics beyond what is already required to improve precision.

But one could go a step further. As the weapon closes on the target and gets to perhaps one half second to impact, the image now approximates 10,000 to 20,000 pixels. Ten thousand (10,000) pixels of a medium size object like a truck or transporter/erector/launcher (TEL) can provide a highly recognizable picture. If that image were sent back over the weapon data link stretched out over the last half second of flight (when the data link is serving no other function), a picture of the target condition just prior to impact could be provided to the shooter or network. This picture could indicate actual cumulative battle damage resulting from all preceding attacks. No technological hurdle prevents this kind of actual BDA; the only thing that is required is to increase the bandwidth of the weapon data link from the few hundred bits per second (BPS) required for midcourse updates to a few tens of kilobits per second (kBPS) to send back a compressed image over a duration of one-half second. There will, of course, be a cost, but it appears minimal.

For this form of BDA, the slower the weapon flies, the better. Some concepts now in their formative stages (e.g., the Loitering Air Missile (LAM) in DARPA's NETFIRES program) might lend themselves naturally toward providing this kind of functionality; such concepts fly relatively slow, can loiter, and can view the target from multiple aspects and send back images as they fly.

The panel recommends that the exploitation of the optical seeking function in developmental weapons for organic BDA purposes be pursued. In addition, the panel recommends that the development of dedicated company-level BDA assets to support the integrated fire support mission should be pursued.

3.10 Conclusions and Recommendations

As ROE continue to evolve and place greater emphasis on rapid but accurate measured response, reduced collateral damage, and minimizing the possibility of fratricide, a growing need exists to improve weapon accuracy.

This study concludes that precision weapons are valuable. They enable our military to apply the appropriate response with necessary accuracy, and they do so while

reducing logistical burden and supporting the goal of a lighter, more mobile, and more effective transformational force. In addition, analysts have shown these weapons to be effective across all target types (fixed and moving, in point and area scenarios). From this we conclude that AT&L should continue to pursue precision weapons development and transition these weapons as soon as feasible to the fielded force.

The panel has struggled to understand the actual cost of delivering a weapon into theater. While weapon procurement cost is available, the associated storage, certification, and transportation costs of moving the weapon from CONUS to the area of concern are not readily understood. Serious concern exists that DoD may not be capable of determining the proper mix of precision weapons if the total cost of weapon ownership is not explicitly identified and shared with development, procurement, and operational components. We therefore recommend the following:

- USD(AT&L) should establish a systems engineering function to quantify the true total *systems* cost of delivery weapons into theater and guide a balanced system acquisition process for weapons/ISR/C-3.
- USD(AT&L) should also revitalize the JMEM process to improve usability of the JMEM toolset and to integrate efforts of JMEM analysts and operations personnel into the design process.

USD(AT&L) has shown effective leadership in driving the performance, packaging, and application of navigation and guidance technology toward affordable solution that will be available to all of the Services engaged in fire support activities. This same leadership should be applied to addressing similar challenges with data link and seeker technologies in order to make precision weapons that will address point and area targets, whether fixed or moving, at an affordable price to the Services. The S&T community led the early way by retiring several of the risks associated with data links and seekers at the component level. AT&L now needs to lead the effort that will bring these component elements together in a system designs that will answer the need of the 21st century warfighter. On this count, then, we recommend that USD(AT&L) stand up efforts that "pull" maturing technology out of the S&T community to make affordable seekers a reality. We recommend further that DARPA revive efforts associated with universally applicable, affordable data links to support the integrated fire support objectives for moving target acquisition and battle damage assessment.

The military has been too aggressive in mandating the implementation of the GPS SAASM requirement in every military weapon system. There are certain military missions and classes of weapons where the capabilities provided by SAASM are neither beneficial nor necessary. In the case of integrated fire support weapons, the SAASM dictate represents a needless over-specification of system requirements. As with any weapon system procurement, this relates directly to affordability. Including SAASM in IFS weapons when the anti-jam requirement can be met through more affordable alternatives should be reevaluated. We recommend, therefore, that USD(AT&L) eliminate the SAASM requirement for integrated fire support weapons.

Timely and accurate BDA is a continuing challenge in today's battlefield environment. Recent military engagements have demonstrated that the increasing pace of engagement increases the demand for BDA, but no effective way exists to meet the demands of soldiers at the brigade level or lower. At this tactical level the availability of

BDA information is unsatisfactory and must be addressed. With the advent of precision weapons, a new capability is now available to field elements that can aid in the improvement of this deficiency. These weapons can now offer the soldier the ability to conduct both predictive and actual BDA activities organically without requesting battalion level or strategic assets (which are most often not readily available). This capability will add flexibility and mobility and will increase the overall confidence of warfighters. We recommend, therefore, that Joint Forces Command (JFCOM) explore useful organic-level BDA offered by modern precision weapons and integrate this capability in mission planning efforts

Furthermore, DoD has inadequately managed the development of dedicated organic BDA assets that would improve the situational awareness of fire support personnel. Numerous programs designed to provide our warfighters with critical capabilities have been underfunded and unfocused. Had DoD better utilized the resources it was provided and recognized the importance of organic BDA to the warfighter, a critical problem in the recent conflict could have been avoided. This deficiency was never before as evident as it was in the recent conflict in Iraq and will only become worse in the future without a change in priorities within the Services. We recommend that the Assistant Secretary of the Navy (ASN) revamp its efforts to develop dedicated BDA assets and avoid the fragmented approaches observed to date—approaches that have denied deployment of operationally ready technologies.

3.11 Summary of Recommendations

- USD(AT&L) should establish a systems engineering function to quantify the true total *systems* cost of delivery weapons into theater and guide the acquisition process for weapons/ISR/C-3.
- USD(AT&L) should revitalize the JMEM process to improve usability of the JMEM toolset and to integrate efforts of JMEMs analysts and operations personnel into design process.
- The Assistant Secretary of the Army/Acquisition, Logistics, and Technology (ASA/ALT) and the Assistant Secretary of the Navy/Research, Development, and Acquisition (ASN/RDA) should stand up efforts to "pull" maturing technology out of the S&T community to make affordable seekers a reality.
- ASA/ALT and ASN/RDA should work with DARPA to revive efforts associated with affordable data links to support the integrated fire support objectives for moving target acquisition and battle damage assessment.
- ASA/ALT and ASN/RDA should continue to support integrated GPS/INS technology with improved anti-jam capability and transition to evolving precision weapon developments (Xcaliber and ERM).
- ASA/ALT and ASN/RDA should extend GPS/INS systems to the development of a Guided Integrated Fuse (GIF) to upgrade unguided weapons to precision weapons.

- USD(AT&L) and the GPS/JPO should consider elimination of the SAASM requirement for integrated fire support weapons.
- ASA/ALT and ASN/RDA should work with JFCOM to explore useful organic-level BDA offered by modern precision weapons and integrate this capability into mission planning efforts.
- ASA/ALT and ASN/RDA should revamp efforts to develop dedicated BDA assets and avoid the fragmented approaches observed to date—approaches that have denied deployment of operationally ready technologies.

4. TACTICAL ISR: SENSORS AND TARGETING SYSTEMS

Having a precise weapon is not enough to achieve an operational precision targeting capability; we must also be able to detect targets, locate them, identify them, and assess damage to them post-attack. We must improve sensors and targeting systems in order to improve the accuracy and effectiveness of the overall integrated fire support system. In this chapter we have assessed current tactical weapon targeting, aided visual indirect targeting, combat identification and blue-force situational awareness, and timely tactical targeting and battle damage assessment. In each case, we identify technologies and approaches to improve our sensing and targeting capabilities.

4.1 Tactical ISR: A Key Element of Integrated Fire Support

ISR sensors and platforms on the battlefield provide target detection, location, target ID, and BDA to support integrated fire support. ISR assets such as electro-optical (EO) sensors, synthetic aperture radar (SAR), surface moving target indicator (SMTI) radar provide multi-phenomenology products that remotely detect and discriminate targets from natural and man-made clutter. The detected targets can be accurately located within the battlespace either directly by the ISR asset or with additional processing applied to the ISR products.

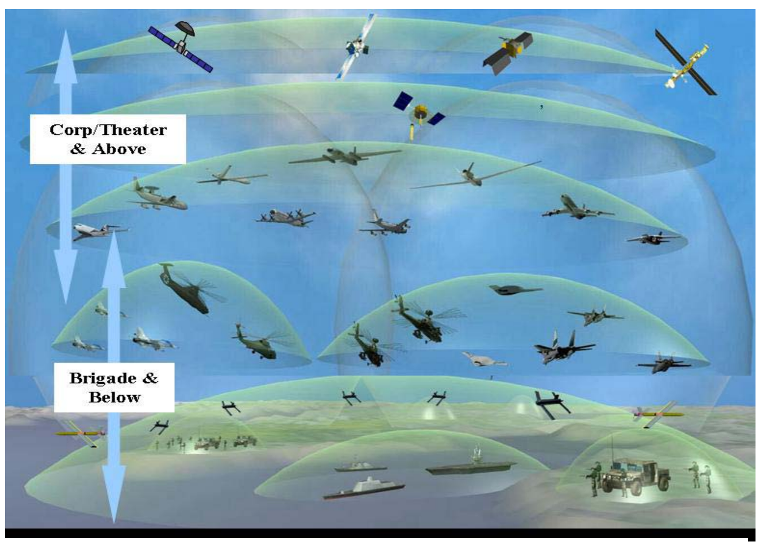


Figure 4-1

The TLE provided by the ISR products and downstream processing provides a fundamental limit on targeting. Previous DSB studies have shown that TLE should be "balanced" with weapon system delivery accuracy to achieve an effective kill chain. Precision TLE and weapon delivery are fundamental to improving efficiency and lethality. They are also essential to reducing collateral damage and fratricide, factors that are becoming increasingly important in an asymmetrical battlespace.

Target identification is essential to effective target prosecution; remote target identification relying strictly on ISR products has proven to be an elusive goal and remains effectively a humans-in-the-loop operation. A key element of target ID is the identification of blue (friendly) forces to minimize fratricide. Finally, ISR assets provide products that support BDA. Like target ID, BDA relying strictly on ISR products has proven to be an elusive goal and generally requires other information as well as humans as part of the decision process.

Platforms, sensors, and products

ISR sensors and platforms can be partitioned into those systems that are managed at the corps and above (theater) level and those that are managed at the brigade level and below (see Figure 4-1). Corps and theater assets include space-based sensors and other ISR systems.[7] Products from these systems are supported by national databases and provide the foundation for the effective precision targeting of fixed targets. In addition, manned airborne platforms such as Joint STARS, U-2, and Rivet Joint and unmanned platforms such as Global Hawk and Predator are considered to be corps and above assets. Brigade and below ISR assets include both dedicated manned airborne sensor systems (e.g., P-3, Guardrail, Airborne Reconnaissance Low) as well as sensor suites that are integrated into manned reconnaissance and strike platforms, including fixed- (e.g., F-15E, F-18E/F, etc.) and rotary-wing (e.g., Apache Longbow) airborne assets.

Figure 4-2: Shadow UAV.

The most noticeable ISR system development activity in recent years has been in unmanned aerial vehicles (UAVs) that are managed at the brigade level and below. Obvious benefits accrue from co-locating rapidly deploying forces and organic ISR capabilities that can be launched and interrogated in a timely manner. Accordingly, the Services are developing and deploying small, relatively inexpensive unmanned airborne assets that are simple to deploy and operate (e.g., Pioneer, Shadow, Dragon Eye, TUAV, etc.).

Figure 4-3

Manned ground targeting systems (both vehicle-mounted and man-portable) have historically played a key role in targeting for integrated fires. Today, laser designating and visual targeting systems represent the state-of-the-practice in line-of-sight targeting. There is also a growing awareness that unattended ground sensors (e.g., Steel Rattler/Eagle, ARGUS, etc.) can contribute information and features to support each phase of ISR's contribution to integrated fires (detection, location, CID, and BDA). Unattended ground sensor technologies, however, are in still in their infancy and have only seen limited use to date.

Imagery products have proven extremely effective when supporting the precision targeting of stationary or fixed targets. Brigade/theater-level assets provide high-quality imagery products and humans provide detection and target ID. The TLE produced by imagery products can be improved to support precision targeting by combining products with national databases. Significant improvements (accuracy and processing latency) have been made in automating targeting

[7] Space-based sensors include those that fall within the category of national technical means (NTM) as well as commercial imagery satellites.

against fixed and stationary targets via imaging and continued progress is expected. Humans are again required to assess BDA via imagery.

EO and forward-looking infra-red (FLIR) sensors have been the primary sources of imagery. Since these products can be affected by weather and environment, there has been some movement toward the use of SAR, which has demonstrated sufficient resolution to support target location accuracy. Still, the community has not yet widely accepted SAR imagery to support either target ID or BDA.

Signals intelligence (SIGINT) systems are very effective at detecting and locating (stationary or moving) emitters but do not have single-platform capabilities that support TLEs for precision location and targeting. SIGINT can play a key role in the target ID process when combined with supplemental information. SIGINT can also contribute features to the BDA process. Surface moving target indicator (SMTI) radar systems[8] can easily detect moving targets but, like SIGINT, often do not have single-platform system TLEs that support precision targeting. SMTI provides some features that contribute to target ID and BDA but cannot be relied upon for these functions. Multi-lateration from multiple platforms has been demonstrated for both SMTI and SIGINT, developing TLEs that support precision targeting. This approach requires simultaneous multiple platforms, communications, and processing.

Significant improvements have been achieved in video sensors and processing, and this technology supports real-time CID and BDA against stationary, fixed, and moving targets, although the systems have a limited field of view and must be cued. Further, current system TLEs do not support precision targeting, but it is reasonable to expect that the TLE improvements via processing that are being developed for high-end EO and imagery can be extended to support video processing. Finally, there is increasing interest in proximity sensing modalities such as acoustic, seismic, magnetic, and so on that can be used to detect and help characterize fixed, stationary, and moving targets. These systems will require multi-lateration for target location.

General observations

A great deal of insight into the future use of ISR systems in support of integrated fires can be gained from reviewing the related lessons learned in recent OIF and OEF activities. From a sensor-use perspective, a tremendous reduction in the sensor data to targeting coordinate cycle for stationary targets has been demonstrated. Also, OIF provided the first deployment of a widely used cooperative BFT, which, although limited, proved extremely effective in providing local situation awareness which in turn helped to minimize fratricide. Remote target ID and BDA remained a vexing problem and still require humans in the loop, although UAVs did through video provide additional "virtual eyes" on targets to support target ID and BDA. Finally, there was a significant increase in the demand for responsive ISR data to support integrated fire support within the asymmetric battlespace.

From an adversary perspective, there are additional lessons learned that must be understood and will greatly impact future ISR asset development, deployment, and utility for integrated fire support. Stationary and fixed targets will be located in difficult (political or physical) to strike locations requiring both precision targeting and precision

[8] SMTI was formerly known as known as ground moving target Indicator (GMTI) radar.

weapons. Further, our adversaries have realized that they are easier to target if they remain stationary. Our adversaries have demonstrated a growing commitment to use mobility extensively. They have also demonstrated the desire to use increasing amounts of camouflage, concealment, and deception (CC&D).

Hence, the trend in ISR platforms and sensors is toward the proliferation of "organic ISR assets" at the brigade level and below to provide responsive ISR products in a dynamic battlespace. These can be made more effective if they are networked with, and take advantage of, the synoptic views and cues from assets at the corps/theater level and above. This will provide the ability to surge ISR capabilities where needed and keep pace with the movement of battle. The network of ISR assets will leverage multi-lateration and processing to improve single-sensor TLE to support the precision targeting needed in the future battlespace. Finally, the network of ISR assets will also provide the multi-phenomenology required to support target ID and BDA and to counter CC&D.

4.2 Tactical Weapon Targeting

Sensor Platforms and TLE Requirements

The basic targeting sensors of interest range from the human spotter—who calls in indirect air, ground, or shipborne fire—to high flying (and potentially space-based) radar and EO/IR sensor systems. Theater assets such as Joint STARS are primarily sensor platforms, whereas tactical aircraft carry both sensors and weapons (the sensors in this latter case primarily being SAR and moving target indicator (MTI) radar and EO/FLIR targeting pods). We discuss the targeting needs of each type below.

There are essentially three classes of weapons in use today, and each places different demands on the targeting system:

1. Unguided munitions,
2. Laser-guided munitions, and
3. Coordinate-seeking weapons.

The most familiar is the ubiquitous *unguided munition*, which basically traverses a ballistic trajectory and has limited precision, suffering the vagaries of ballistic dispersion and related effects such as surface winds. To compensate for these errors, visual observers or "spotters" are used to observe where an initial round impacts then issue correction commands to the shooter to "walk" the impact points of successive rounds onto the target. An added benefit of visual targeting is target ID and immediate BDA.

Laser-guided munitions, on the other hand, are very precise and basically strike a laser designation spot. The laser designator can be aimed manually by a forward-based spotter who places the crosshairs of an optical sighting device (boresighted with a laser designator) on the target to guide an indirect fire weapon. Laser guided bombs can also be very effectively guided by airborne illuminators (generally used in conjunction with a FLIR or television (TV) imaging system). In many cases, the quality of the image available to the operator is not sufficient for target ID, although reasonably good BDA is generally possible.

Coordinate-seeking weapons such as the Joint Direct Attack Munition (JDAM) rely on a variety of techniques for target designation. These techniques range from coordinates obtained from previously obtained target databases (in the case of preplanned

missions) to real-time target detection and designation using on-board sensors such as airborne radar of FLIR/TV systems. For situations where standoff range is important, the angular errors of most airborne sensor systems introduce an unacceptably large TLE, and thus some method is needed to obtain additional accuracy. Representative sensors and associated TLEs are shown in the table below.

Sensors	TLE today	Required TLE	Technique(s)
Space-based	Classified	Classified	DPPDB and GRIDLOCK
Theater airborne	Up to 100s of m	<4m	GRIDLOCK
Tactical airborne	10s to 100s of m	<4m	GRIDLOCK
Vehicle-mounted visual	7-16 m at 10 km	5-10 m at 10 km	Some development required
Man-portable visual	Up to 200 m at 10 km	5-10 m at 10 km	Significant development required
Counter-mortar/ counter-battery (TPQ-36/37)	30 m (range dependent)	5-10 m (range dependent)	Some development required

Table 4-1: Tactical weapon targeting: sensor target location error.

A very useful technique is a process known as "GRIDLOCK," which makes use of previously obtained reference imagery (in the form of the Digital Point Positioning Data Base) containing accurately located geographic points. By precisely registering a given real-time image of the same area with the reference image, very small TLEs can be achieved, as described in the next section.

"GRIDLOCK"—A Common Reference for Joint Operations

"GRIDLOCKING," or accurately registering tactical airborne imagery to the Digital Point Positioning Data Base (DPPDB), appears to be an almost universal method that will facilitate unambiguous, precise targeting by the joint force. However, today's routinely achievable target location accuracies derived from space-based or airborne imagery currently appear to be of substantially higher quality than that obtainable by man-portable or other ground-based optical systems. This is of particular concern when it is noted that these ground-based systems generally provide the targeting information for relatively low-yield weapons, while the space-based and airborne imagery generally provide targeting for much higher-yielding weapons, making that overall construct more effective. It is clear that the ground-based targeting community, with its lower-yielding supporting weaponry, needs to make great technical strides in order to efficiently support their mission needs.

In 2001, the DSB Task Force on Precision Targeting recommended that the DPPDB become the de-facto standard for joint precision targeting, and that an approach know as GRIDLOCK be employed to register timely (but often inaccurate) tactical imagery to the national DPPDB standard. The DPPDB consists of accurately located stereo-pair imagery provided by the National Geo-spatial Intelligence Agency (NGA). Although the database is large (even a relatively small area, 60 nmi x 60 nmi, occupies 10 to 15 GB, it is being increasingly used by ground forces, who register their organic tactical imagery to the DPPDB ("GRIDLOCK" their imagery) and transfer highly accurate "national" coordinates to timely organic imagery.

GRIDLOCK is also the name of an ongoing ACTD that will provide real-time field demonstrations of this capability as applied to Global Hawk imagery in Joint Expeditionary Force Experiment (JEFX) '04, and will be working to improve the speed and automation of the process. The process to be demonstrated by the ACTD is only the first step in "rolling out" the GRIDLOCK capability to the joint targeting community.

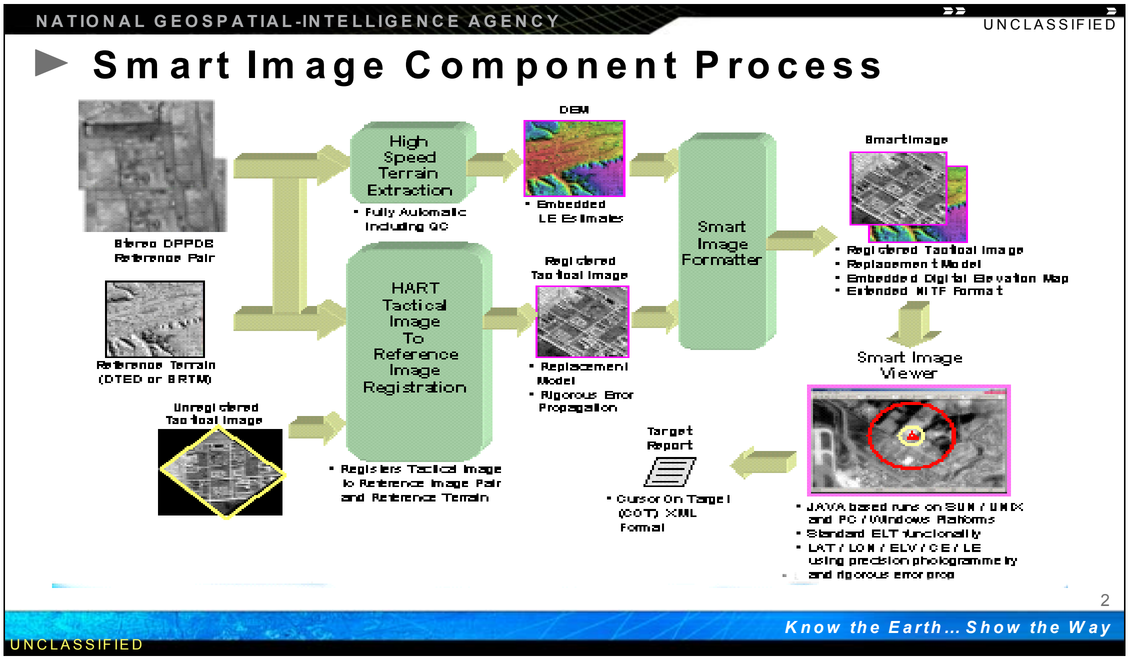


Figure 4-4: GRIDLOCK ACTD processing concept.

Today the DPPDB database occupies a lot of "real estate" in terms of bulk storage, making it difficult for some users to access. However, with the meteoric improvements in $/GB and GB/ in3 that are occurring due to the natural evolution of the commercial market, it is anticipated that this momentary difficultly will correct itself within the next few years. USB "flash drives" that supported only 128MB of memory 2 years ago, are currently available with 1 GB, and 2- and 4-GB models will be available within a year. This explosion of cheap removable memory is probably *the* technology that will facilitate the widespread distribution of the DPPDB to the Joint Force within the next 5 years. The only other impediment to the widespread deployment of this technology is the sheer computing power required, which, as we know, still benefits from Moore's Law.

Counter-mortar/counter-battery systems

For ground units on the move, one of the most used organic targeting systems has been the counter-mortar/counter-battery (CM/CB) radar, which essentially detects enemy projectiles, tracks and establishes their trajectory, and then rapidly computes their likely coordinates of origin through track extrapolation techniques. Accuracy of these systems depends on the CM/CB radar characteristics and the situational geometry of the projectile track relative to the location of the sensing radar. Most of the current CM/CB radars are of legacy vintage and do not make use of the most sophisticated techniques now available (e.g., highly agile active apertures with adaptive digital beam forming, super-resolution

signal processing, and other approaches for enhancing track accuracy and trajectory estimation). Given the demonstrated utility of this class of sensor systems, it would be prudent to conduct additional R&D to develop improved capabilities. It is estimated that the accuracy of current systems can be improved by at least a factor of two and perhaps by more that an order of magnitude simply by applying currently available solid state technology and much more powerful signal processing capabilities.

4.3 Aided Visual Indirect Targeting

For purposes of bounding the targeting problem for visual designation, we will define the goal of "precision targeting" to be an accuracy of 10 m. This represents an accuracy that is much better than the performance of historical indirect fire systems and achieving it will provide dramatic efficiency (kills per round) and collateral (fratricide per kill) advantages. Because achieving accuracy can result in an operational cost that increases non-linearly, careful choice of the accuracy goal is important. We selected 10 m based on the upcoming Excalibur precision weapon, which has a weapon delivery accuracy of 10 m. While other air-dropped weapons with higher precision do exist, the Excalibur is likely to be used extensively in future conflicts. To achieve a balance of error contribution and cost between targeting and weapon delivery, then, we have chosen to also define the target location accuracy goal as 10 m.

Direct targeting and the targeting of enemy air defenses, fixed assets, and strategic capabilities has led to the evolution of a complex variety of ISR and target acquisition systems using both EO and RF signals and automated recognition algorithms. Most of the air strikes that occur in theatre employ targeting systems of this type. Conversely, a very large percentage of indirect fires used in support of ground maneuver is called in with "eyes on target" combined with a measurement or designation of location. Thus visual-based targeting systems are of particular importance to the conduct of ground operations.

While a lot is to be gained from automated recognition capabilities, human recognition retains the highest recognition performance. The ability to distinguish objects, recognize and classify threats, and recognize and adjust for the potential for collateral damage are integral advantages of a targeting system that has a human interpreter. While human observers are excellent for recognition, however, they depend on the visual targeting system for magnification, night viewing, and especially orientation and target location determination. The magnification, night viewing, and ranging capabilities of today's vehicular mounted systems are reasonable. However, man-portable systems have significant deficiencies. Chief among them is the inability to determine the absolute pointing direction accurately, which precludes the ability to locate objects precisely.

In the following discussion, we group visual targeting systems into the broad categories of *vehicular* and *hand portable*. We also discuss the distinct targeting modes of geolocation for GPS guided weapons and laser designation for semi-active laser weapons. We do not discuss direct-attack weapons and their targeting systems, except as they also relate to indirect targeting.

Existing indirect fire targeting systems produce target coordinates and sometimes accuracies. As systems move to precision targeting of moving objects, that information approach will become inadequate. If the approach taken is to transmit a sequence of fixed precision observations of 10 m resolution to represent the state of a moving object and

allow the weapon to perform the projection of future target state, it will place a large demand on communications bandwidth and communications latency for the overall system to be effective. It will be preferable for future visual precision targeting systems to be able to track and estimate target trajectory and report that to the network in order to reduce the demand for low-latency between sensor and shooter and to reduce the amount of communication required.

Vehicle-mounted aided visual targeting

The vehicles that were considered for this report were the TUAV, the Bradley Fire Support Team (BFIST), the Knight fire support vehicle (FSV), the Kiowa helicopter, and the M3A1/A3 Bradley.

	Max Range	Nom Range	Median 2D TLE	Source
TUAV EO/IR	3km (T) 5km (O)		195 m	USA_Eval_Ctr
BFIST A3		10 km	7 m	USA_Eval_Ctr
Knight FSV		10 km	9 m	USA_Eval_Ctr
Kiowa			14.2 m	USA_Eval_Ctr
M3A1/A3 Bradley		10 km	16.3 m	USA_Eval_Ctr

Note: With the exception of the TUAV, these target location errors roughly meet the precision criterion of 10 m and they typically do so at ranges out to 10 km. There are some weaknesses in these systems. Some systems are poorly integrated.

Table 4-2: The status today—representative platform TLEs.

In the document "3ID(M) DIVARTY Observations from OPERATION IRAQI FREEDOM," Colonels Torrance and Nicolle point out the following about the BFIST:

- It does not have a mounted laser designation capability. The only way for a BFIST crew to designate a target is to dismount and set up the Ground/Vehicular Laser Locator Designator (G/VLLD), which takes up half of the internal crew space when stowed. This is not practical during offensive operations.
- The optics package on the BFIST requires the crewman to switch between two separate modes, "Direct Fire Mode" and "FIST Mode." Company fire supporters cite the need for one fire control sight to alleviate the need to change sights between these two modes. The time required to change over hampers indirect fire target acquisitions and increases the risk due to local threats.
- BFIST direct-fire sites are effective out to the maximum range of the Bradley TOW weapon system (3.7 km). The Long-Range Scout Sight (LRSS) for indirect-fire in contrast, can acquire targets beyond the 10 km range with great clarity. Permitting LRSS to be used for direct-fires on the BFIST would significantly upgrade the ability to acquire and identify such targets before maneuver forces close into enemy direct fire range.

Of the current vehicular visual targeting systems, the targeting platform that needs most dramatic improvement is the TUAV. Accuracy on the order of 195 m at ranges of 3 to 5

km is inadequate for precision fire, and lack of a thermal imaging system makes it unusable in dark night conditions. Since the subsystem technology needed for the TUAV is quite small compared to other vehicles, it may well be that the improvements called for below under hand-portable systems will result in technology that can also benefit the TUAV. On vehicles such as BFIST, feedback from Operation Iraqi Freedom points out the need for a greater degree of integration of vehicle visual systems and laser designation systems to provide the crew with overall situation awareness—both information required to steer or drive the vehicle as well as targeting situational awareness (SA), resulting in more effective capability and reduced crew burden.

Vehicular targeting and weapon systems should be enhanced in future generations to permit aided manual tracking in order to provide target velocity vector data in addition to only position information. This will improve accuracy against moving targets and will also provide more useful situational awareness of target locations over time.

Man-Portable Aided Visual Targeting

Table 4-3 displays the performance of some sample man-portable systems. These performance levels (especially at medium and long ranges at night) are far less than "precision" requires.

System	Range	3D Median TLE (M)*	Source
LLDR/day	10 km	17/43/117	JCAS_Test
LLDR/Night	10 km	35/90/201	JCAS_Test
LH-40C/day	10 km	15/28/58	JCAS_Test
LH-40C/night	6 km	11./25	JCAS_Test
Mark VII/day	10 km	20/68/161	JCAS_Test
Mark VII/night	6 km	11./21	JCAS_Test
Vector 21/day	10 km	28/78/103	JCAS_Test
Vector 21/night	6 km	19/62	JCAS_Test
Viper II/day	6 km	17/52	JCAS_Test
VIper II/night	6 km	27/165	JCAS_Test

* Note: Location accuracy for short (.5-3 km)/medium (3-6 km)/long (6-10 km).

Table 4-3: Performance of select man-portable aided visual targeting systems.

The following observations apply to man-portable visual aided targeting systems:

- Geolocating systems (those other than LLDR) have reasonable size (large binoculars), weight (roughly 4 lb.), and cost (roughly $15,000 to $30,000).
- Laser designation systems such as LLDR are too heavy (32 lb.), too large, power hungry, and too costly ($250,000). However, unlike the other systems, LLDR does include a thermal sight, which permits long-range use at night and use in complete darkness,. Even so, improvement in the above parameters is needed.

- Hand-held designators require knowledge of “down” and “north” to determine the relative location of a target from the current position. The determination of “down” is accomplished with an electronic inclinometer which measures the local gravitational field. Stephen Malys of NGA reports that deviations of the local gravitational field rarely amount to more than 0.1 milliradian, or a 1 m error at 10 km.

  The measured performance of the designators in the previous table for pointing are given below:

	Median Az Error (mils)	**Median Elevation Error (mils)**
LLDR/Day	6.4/4.5/5.7	6.8/6.3/6.7
LH-40C/Day	7.7/5.4/6.4	1.5/1.5/1.7
Mark VII	13.5/13.4/13.3	1.2/1/1
Vector 21	21.1/20.9/11	0.5/0.6/0.6
Viper II	9.6/13	

Note: Some of the inclinometers are providing elevation accuracies of 5 m at 10 km, which is adequate for most purposes.

Table 4-4: Pointing accuracy of select man-portable aided visual targeting systems.

- Azimuth pointing accuracy is much worse than elevation. This occurs for these systems and not for the vehicle mounted systems because the compasses in current generation hand-held systems are magnetic. This approach has many inadequacies for precision targeting.
  - The local magnetic deviation is not easily predicted. Even with the best available charts, errors due to deviations in the local field can be of the order of tens of milliradians, which will cause hundreds of meters of error.
  - Even if the local deviation were known, the JCAS organization found that self-influence of the local field either due to metal objects on the person or insufficient care during a substantial calibration process could generate similar errors.
  - Finally, the calibration process itself takes significant time and requires the operator to perform a series of substantial movements reorienting the compass in many directions to accomplish the calibration.
- Near-IR imaging is limited to short ranges without illumination. The JCAS test group also found that the generation of night vision equipment used in all but the LLDR designation system depends upon ambient illumination. This limits range on most nights, and on moonless and cloudy nights it limits it to hundreds of meters.

The following list summarizes proposed system improvements in the area of man-portable visual aided targeting systems:

- Improve geolocation accuracy to 10 m TLE at 10 km. Based on emerging technologies such as compact fiber or micro electro mechanical systems

(MEMS) gyros and self-calibrating inclinometers it is possible to develop a next generation hand-held targeting system with an error of 10 m at 10 km.

- Achieve "dark-night" operation out to 10 km. Such a system should employ a thermal sight (leveraging the recent investments in thermal weapon sights) to permit operation at full range in complete darkness.
- Narrow the range finder beam by a factor of four. The rangefinder and designator beams should be reduced from the .5 milliradian spread to more like .1 milliradian to assure the ability to illuminate the target unambiguously at 10 km.
- Develop a practical laser designator.
  - The existing 32 lb LLDR configuration is seen as an excessive burden by soldiers and its $250,000 price makes broad fielding unfeasible. A more practical designation option which reduces size by a factor of five, weight by a factor of 10, and power by a factor of five should be achieved for these systems. Note that with the deployment of lower echelon semi-active weapons like the Precision Guided Mortar Munition (PGMM), the need for wider availability of designators will increase.
  - It is conceivable that a more limited power output and therefore weapon lock range (little power is lost on the way to the target due to the narrow beam) would permit development of a dual-mode laser integral to the rangefinder.
  - Enable stabilized operation. The technology that has been developed for image stabilization in high-quality cameras and video equipment would be a valuable addition to these hand-held systems. The cost of adding those capabilities to commercial telephoto lenses is measured in the hundreds of dollars. The addition of stabilization would allow the current tripod to be eliminated for many uses providing for more effective tactics and operational convenience.
- *Size and cost targets*:
  - Given the current price point of $25,000 without designator and the current weight point of 4 lb., and given the need to add thermal sights, stabilization, and a more precise laser system, reasonable goals for the system would be 7.5 lb weight without laser designator, 12.5 lb with laser designator and $75,000 cost without laser designator, $100,000 cost with laser designator.
- *Needed technology development*. In order to achieve these goals, DoD should undertake the following S&T goals:
  - Low-cost fiber laser or equivalent North seeking gyro with .5 mrad accuracy,
  - Low-cost integral thermal imaging (leverage Thermal Weapon Sight investments),
  - Low-cost eye safe 0.1 milliradian ranging laser (diffraction limited),
  - Low-cost, lightweight, > 20 percent efficient designation laser, and

- Low-cost image and beam stabilization.

4.4 Combat Identification (CID) and Blue Force Situational Awareness

After decades of effort and billions spent on both cooperative identification friend or foe (IFF) systems and non-cooperative target recognition (NCTR) approaches, we have only a marginal theater-wide CID capability. Recent fratricide incidents in OIF are tragic examples of this deficiency and are but a small fraction of what could happen under less favorable circumstances against a more capable adversary.

Cooperative systems have historically been plagued with a fundamental issue: if the IFF system is inoperative due to a malfunction or an operator intentionally turns it off, there is no inherent method for a "shooter" to distinguish the resulting lack of response from that of an enemy (red) target. Also, many friendly (gray) targets are not equipped with IFF gear, making a response to a "shooter's" interrogation impossible. Recently, urban targets and individual enemy personnel—often in close proximity and intermingled with gray components—have become frequent and high priority targets, where complex and expensive cooperative IFF systems are totally impractical.

Non-cooperative target recognition systems are useful against expensive aircraft and certain vehicular targets, but in general are not effective against the majority of other target candidates. This situation is exacerbated with the emergence of urban warfare as a frequent and high priority occurrence. From this it is clear that another approach is required if we are to make a significant improvement in this complex but critical area.

As mentioned above, there are three components to the "target" population:

1. "Red" (enemy forces, vehicles, or individuals);
2. "Gray" (friendly or neutral target candidates); and
3. "Blue" (U.S. or coalition forces, vehicles, or individuals).

True combat ID requires situational awareness (i.e., location and identity) of each one of these three target candidate categories, but the location and identity of *red* and *gray* are quite often unknown most of the time. However, recent deployment of blue-force tracking capability proved to be of major benefit in OIF for at least removing the uncertainty associated with our own forces. This suggests that a more comprehensive deployment of this approach, with guaranteed low latency and employed on essentially all blue elements, would provide a quantum improvement in the CID arena.

The concept of BFT was recently introduced very successfully in Operation Iraqi Freedom through employment of the Force XXI Battle Command Brigade and Below (FBCB2) system, where at the end of formal hostilities, ground elements in various parts of the entire theater were using it. By and large, FBCB2 was received enthusiastically by the troops and has been credited with preventing more than one incident of potentially very serious fratricide. It makes use of existing communications and satellite links and was available down to elements such as individual tank commanders. BFT employs modern network technology and demonstrated an impressive capability to adapt to rapidly changing situations.

The unfolding expansion of DoD global communications capability through programs such as the Transformational Communications System, Joint Tactical Radio

System, and the Global Information Grid, along with the availability of small, low-cost GPS transceivers, now makes it feasible to expand the existing blue force tracking concept to the entire friendly force. With essentially all elements of the force precisely reporting their up-to-date position on a timely basis, the ability to minimize fratricide can be reduced by a very large amount while simultaneously enhancing the warfighter's offensive effectiveness.

The construct for an improved and significantly expanded blue force situational awareness (BFSA) approach would have the following cardinal attributes:

- Ubiquitous deployment of accurate GPS/self-location transceivers that aperiodically report precise present location. Like the current BFT system, the reporting rate would vary from a minimum of, say, once per 5 minutes for a stationary location to appropriately more frequently on a moving location, such that the reported location did not differ from the actual by more than a prescribed amount (e.g., 50 m).
- In the objective system, these GPS/transceivers would be deployed on every blue force asset (possibly down to the individual foot soldier).
- This blue force position information from each individual report would be received and assimilated by a local hub and forwarded up the hierarchal chain. This composite local picture would be transmitted periodically back to each local site with a need to know to provide them SA on their local area. The next level in the hierarchy would aggregate information from several local sites and pass along the composite picture both to higher as well as lower echelons.
- Higher-level hubs would mosaic multiple local area BFSA "pictures," forming a composite BFSA view of increasingly larger areas, and then transmit this up and down the network hierarchy. This composite information would be available to all on the network with an appropriate need-to-know.

Although BFSA is in broad terms a cooperative system, it has several characteristics that avoid most of the pitfalls associated with conventional IFF systems. In particular, an individual node in the system is able to see itself in its local picture; absence or error in this position can thus be self-detected and reported through other communication channels in most cases. Further, if a friendly strike aircraft or other source of fires plans to launch a weapon against a specific target location, for example, a friendly located at or near that location can send a "don't shoot" priority message to avoid a fratricide incident.

This of course requires a good multi-level access encryption process built into the BFSA system to avoid exploitation by an adversary, which suggests the need for inclusion of a robust over-the-air key transmission process, etc. Additional techniques for attaining one's own coordinates precisely (supplementary to GPS, especially in urban environments)—such as the "Network Assisted GPS" technique now employed by the cell phone industry—should be explored.

4.5 Timely Tactical Targeting and Battle Damage Assessment

Remote targeting and responsive BDA remains a problem for integrated fires when it is not possible for human observers to be present. Development activities that will provide increasingly longer range weapons will exacerbate this problem and there is the increasing need to develop tactical sensors that can provide “virtual eyes” for target ID and for BDA.

There is a corresponding significant amount of activity to develop small UAV-based video systems to support rapid target ID and BDA. However, these systems do not have the inherent accuracy to support precision TLEs that will be needed to balance future precision weapon systems. There have been some limited S&T activities investigating the ability to “grab video frames” and process these with existing databases to provide additional sensor system targeting accuracy. These S&T activities should be supporting and encouraged to mature.

Researchers have investigated technologies that may provide an inexpensive solution to providing BDA for long-range artillery and rocket systems. In the late 1990s, several organizations investigated the feasibility of innovative ISR assets that were dedicated, or responsive, to address the BDA mission for these weapon systems. The key concept was that of an ISR “round” that was launched in a similar manner to artillery (gun or missile) systems. The ISR round would have longer loitering capability than the weapon round and would also have a data link such that the ISR round could loiter at the target site and provide real-time BDA information. Obviously, the ISR round could also be launched prior to launching the weapon itself and could provide timely “virtual eyes” that are “on site” at the targeting location.

Several S&T programs (WASP, Quick-look, SOAR, etc.) have investigated the supporting technology for this capability. One of the most attractive approaches is the use of small, man-portable UAVs equipped with visible TV cameras or uncooled IR cameras. However, the Services have failed to adequately fund and pursue this capability and none has been fielded. Figure 4.5 identifies a number of potential organic autonomous vehicles that could be utilized to provide target ID and BDA.

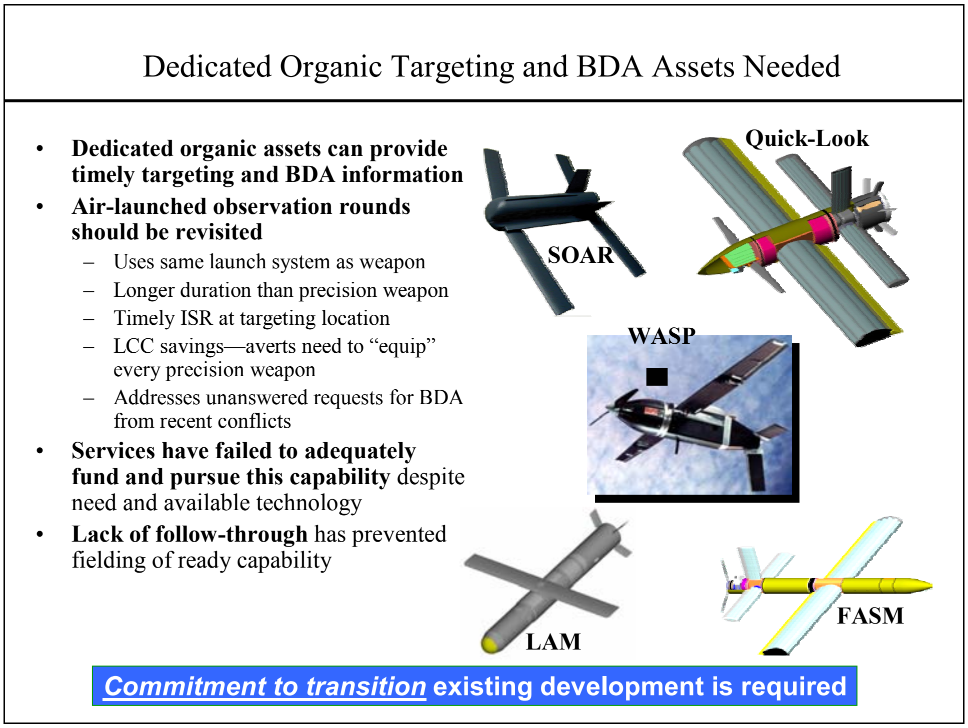


Figure 4.5: Typical tactical bomb damage assessment assets.

4.6 Summary of Recommendations

- The Under Secretary of Defense for Acquisition, Technology, and Logistics (USD(AT&L)) should continue support for the GRIDLOCK ACTD and field the capability.
- The Services should universally adapt the GRIDLOCK capability to all tactical and theater airborne imaging sensors and make it a requirement for all new such systems.
- The Assistant Secretary of the Army (Acquisition, Logistics, and Technology) ASA(ALT) and the Assistant Secretary of the Navy (Research, Development, and Acquisition) ASN(RDA) should focus and coordinate efforts to develop tactical UAV systems for organic surveillance with improved TLE and BDA capabilities.
- ASA(ALT) and ASN(RDA) should establish a vigorous S&T program to develop a technical base to improve target location accuracy of TUAV, vehicular, and man-portable targeting systems.
- USD(AT&L) and the Assistant Secretary of Defense for Networks and Information Integration (ASD(NII)) should develop a theater-wide joint blue force CID system. All tactical networked radios should be configured to incorporate network-assisted GPS capability.

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5. BATTLE MANAGEMENT, COMMAND, CONTROL, AND COMMUNICATIONS (BMC^3) FOR INTEGRATED FIRE SUPPORT

Fires support the actions of friendly forces by disrupting, delaying, or damaging enemy forces through close, deep, interdiction, and counter-battery fires. As the scheme of maneuver in recent conflicts has become more non-linear and more distributed, the complexity of supporting maneuvers with fires has increased. With the advent of extended range, coordinate-seeking munitions, the number and ways in which fires can be employed in support of maneuver will increase substantially. With increased range and precision, fires will grow in potency as a supporting arms option, reducing its own vulnerability and increasing the span of potential targets. To plan and execute timely, safe and effective joint fires, a complex set of decisions relating to allocating and executing targeting and attack resources is required. To take advantage of the full potential for joint fires and close air support in a future characterized by non-linear battlespace operations, zero tolerance for fratricide and collateral damage and emerging expanded capabilities in coordinate-seeking weapons (CSW), there must be a commensurate improvement in the approach that our forces employ in command and control for fires, both within the Services and in joint fire support across Services.

A variety of mechanisms for planning and executing targeting and fires both within and across services have been established through on evolutionary process that has spanned the past century. Those mechanisms serve two main purposes: effectiveness and safety – both of which are equal in importance. Effectiveness relates to achieving effects desired by the maneuver commander to support operations, and safety relates to ensuring that friendly forces and non-combatants are not put in harms way by our fires. These mechanisms have evolved over time into what has become a complex patchwork of decision-making and execution procedures that can, at times, be both slow and cumbersome. With the evolution of increasingly reliable and pervasive digital communications and fast and powerful tools for aiding commanders in decision-making and execution monitoring, it is time to rethink the approach to BMC^3 that our military employs both within and across Services in supporting operations with joint fires and close air support.

5.1 Evolution of Precision Guided Weapons

We have begun to see a proliferation in the development of precision weapons (coordinate seeking and discriminatory) that includes the small diameter bomb and a variety of extended range munitions (Excalibur, Extended Range Guided Munition (ERGM), the Army's Multi-Role Armament and Ammunition System (MRAAS), variants of the Joint Common Missile, extended range guided multiple rocket launch system (GMLRS), and, further in the future, the possibility of an extended-range kinetic energy (KE) railgun projectile). Typically these weapons deliver relatively small amounts of high energy explosive (HE) mass; and, consequently, their effectiveness depends both on accurate weapon delivery guidance, navigation, and control (GN&C) and on commensurate TLE.

Employing artillery-launched extended-range munitions represents the potential for large numbers and a broad range of types of targets that can be addressed with this

class of weapons during relatively short periods of time. As noted earlier, their effectiveness depends in large part on TLE being commensurate with the weapon's CEP, with the added benefit of being able to address targets in close proximity to blue forces, non-combatants, cultural sites, etc. Achieving small TLE, positive target ID and possibly BDA for large numbers of targets requires a commensurate tasking of supporting ISR. The associated large numbers of weapon-sensor-target allocation decisions as well as the need for timely decision-making (reduced latency) will expand the decision-making burden on command and control elements for joint fire support. Finally, assuming that an auxiliary objective is to choose the best available sensor-weapon combination across Services—air, land, and sea—within latency constraints poses an additional significant challenge to joint fires command and control.

5.2 Joint Fires Today: Coordination of Service Systems

The following is an excerpt from Joint Pub 3-09:

> ***The JFC is responsible for ensuring the synchronization and integration of fires.*** *The JFC must have systems that allow rapid response to changes as they occur. In this effort, liaison elements play a pivotal role in the coordination of joint fire support. The challenge for the JFC is to integrate and synchronize the wide range of capabilities at the JFC's disposal to achieve the campaign and/or operation objectives. The JFC's intent will often be to bring force against the opponent's entire structure in a near simultaneous manner that will overwhelm and cripple the enemy's capabilities and will to resist.*

Currently a variety of service organizations participate in making decisions related to exploiting joint fires, the allocation of targeting resources and the distribution of Close Air Support (CAS) sorties in shaping the battlefield to assist maneuver objectives. These joint fire support decisions require coordination and integration of airspace as well as coordination of air and surface-to-surface targeting and attack resources.

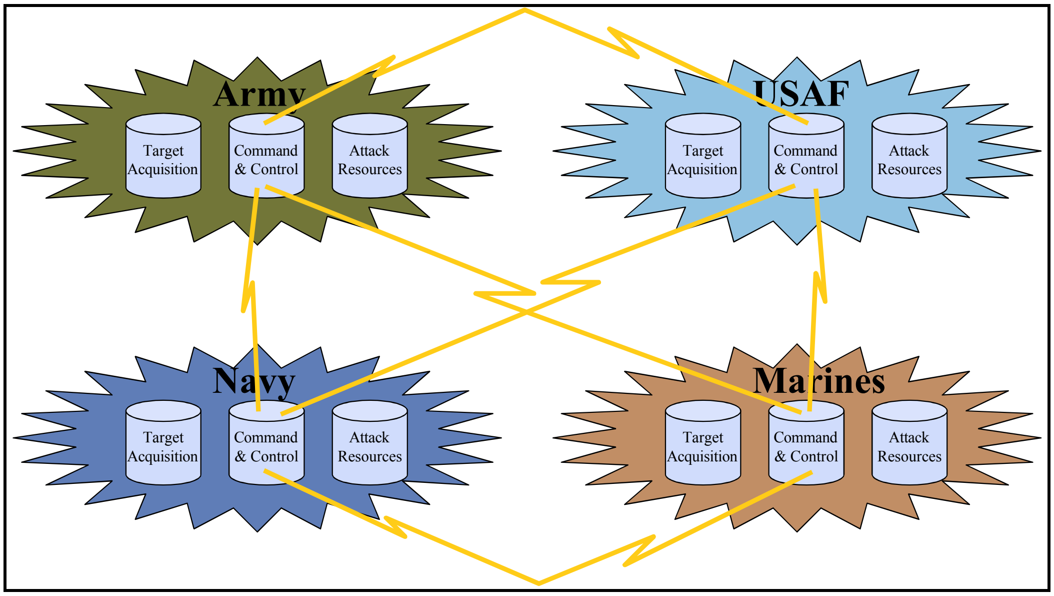

Figure 5-1: Coordination within and across Services occurs via a variety of liaison functions.

Table 5-1 summarizes the main Command and Control (C^2) applications and suites employed in planning and executing fires and strike. Table 5-2 lists the agencies/elements within the Services that serve as coordination elements in support of planning and execution. Although these agencies work closely together to achieve mission objectives, they are separate organizations run by their respective service component commander. A joint agency has not been established to coordinate fire support; rather, liaison officers are assigned to facilitate communications between the agencies. The emphasis should be on integration rather than coordination to achieve mission success.

System	Description
AFATDS: Advanced Field Artillery Tactical Data System	AFATDS is a suite of decision support tools employed by the Army and Marine Corps to help plan, coordinate, and control fires. In supporting this decision-making, AFATDS takes into consideration the state of available fire support platforms, commander's intent and firing solutions based on JMEM effectiveness models.
ADOCS: Automated Deep Operations Coordination System	ADOCS supports planning, coordinating, and managing data for deep operations fires. It displays friendly and enemy unit locations, air corridors, restricted fire areas, etc.
TBMCS: Theater Core Battle Management System	TBMCMS handles target nomination, approval, prioritization, and air asset resource allocation for planned and immediate/time-sensitive targets. It allocates and assigns assets for close air support (CAS).

Table 5-1: Current Service systems for joint fires/strike in support of maneuver elements.

Service	Fire support C^2 agencies
Army	• DOCC: Deep Operations Coordination Cell • FSCOORDs: Fire Support Coordinators • BCD: Battlefield Coordination Detachment (located in AOC to coordinate with JFACC)
Navy/Marine Corps	• SACC: Supporting Arms Coordination Center (coordinates artillery and naval surface fires) • NTACS: Navy Tactical Air Control System (plans and controls Navy air ops including CAS via the ASCS (Air Support Control Section)) • FSCC: Fire Support Coordination Center (coordinates all forms of fire support) • TACP: Tactical Air Control Party (advises maneuver units re supporting air missions) • SFCP: Shore Fire Control Party (liaison between Marine artillery and maneuver)
Air Force	• ASOC: Air Support Operations Center (Coordinates CAS for maneuver forces) • ABCCC: Airborne Battlefield Command and Control Center (Airborne ASOC) • Air Force TACP: Control element stationed with Army combat unit
Special Ops	• SOF Fire Support Coordination: Liaison between SOF and other service elements • SOCOORD: Special Operations Coordination Element (liaison with MEF or Army Corps)

Table 5-2: Inter/intra-Service fire support C^2 agencies.

Each of the services has begun or has plans for improvements to their C^2 systems for fire support as outlined in the table below. However, none of these is specifically targeted for improving *joint* fire support. Rather, they will remain service-centric systems that will continue to provide joint fire support via coordination/liaison functions. That is, there are no plans to further improve, streamline, or standardize on inter-service coordination.

System	Description
Army NETFIRES (FY08)	It will enhance AFATDS to improve its ability to plan and execute fires for emerging coordinate-seeking and loiter type rocket/missile munitions. In addition, it will employ improved considerations for airspace management/deconfliction.
Navy/Marine Corps FORCEnet (Block1 FY06, Block2 FY10, etc. …)	FORCEnet is a network-centric concept that will support improvements to C^2 decision-support. The objective is improved integration of sensors, networks, command and control, platforms, and weapons into a networked, distributed combat force. Furthermore, the objective is to build a scalable capability that spans support for seabed to space and sea to land.

Naval Surface Fire Control (NSFC) System	The NSFC has been proposed as a mission-planning system for Naval surface-fire support that will be interoperable with future Army and Marine Corps fire support systems. The maritime variant of ADOCS has been chosen as the baseline for NSFC.
Air Force AT-AOC (FY08)	Advanced Technology AOC (AT-AOC) represents enhancements to the suite of AOC applications that will enable EBO through improved dynamic tasking. A further objective is to enable distributed C^2 from fixed, deployed, afloat, or airborne platforms.

Table 5-3: Currently planned evolution of Service systems.

The primary C^2 challenge for integrated fire support is to transform this collection of multi-Service fire support functions—initially conceived to operate independently—into a net-centric system in which the globally (across Services) most favorable sensor(s) and weapon(s) are effectively deployed against each target. In particular, this transformation represents a system design that employs the minimum degree of coordination required to ensure safe, timely, and effective supporting fires. Here safety refers to clearance of fires, deconfliction of fires and air traffic, and, in general, adherence to established ROE. Timeliness is critical when addressing moveable or fleeting high-valued targets. Each coordination element represents an "intervention point" in the decision-making chain that may contribute to increased latency.

5.3 Joint Close Air Support

The following is an excerpt from Joint Pub 3-09.3:

> ***Close air support (CAS) can be conducted at any place and time friendly forces are in close proximity to enemy forces.*** *The word "close" does not imply a specific distance; rather, it is situational.* ***The requirement for detailed integration*** *because of proximity, fires, or movement* ***is the determining factor****. At times CAS may be the best means to exploit tactical opportunities in the offense or defense. CAS provides firepower in offensive and defensive operations to destroy, disrupt, suppress, fix, harass, neutralize, or delay enemy forces.*
> *The JFC normally exercises operational control (OPCON) through component commanders. Most CAS in support of joint operations is allocated and tasked via the JFACC staff located in the joint air operations center (JAOC), using host component organic command and control (C^2) architecture.* ***Reliable, secure communications are required*** *to exchange information among all participants. In joint operations,* ***components provide and operate the C^2 systems****, which have similar functions at each level of command.* ***The JFACC tasks air capabilities/forces made available for joint tasking through the JAOC and appropriate Service component C^2 systems.***

Like sea and land-based fires, CAS supports the objectives of the maneuver element. As suggested by an analysis of air strike missions from OIF in Table 5-4 below, CAS and kill box Designated Mean Point of Impact (DMPIs) outnumbered strikes of pre-planned targets by nearly an order of magnitude. Although there were a large number of *planned*

strikes in support of the land component—12,893—only 234 of those targets were actually prosecuted due to the highly dynamic nature of the battle and the substantial lag between the time targets are nominated, approved and placed on the Air Tasking Order and the time at which that Order is executed. Those targets either moved or the original purpose for their being assigned was overtaken by events.

OIF Strategy to Task Mission Areas	In JIPTL	Struck
Maintain Air Supremacy	2,124	1,441
Support Land Component	12,893	234*
Suppress Iraqi Regime	4,559	1,799
Suppress TMD/WMD Delivery Systems	1,840	832
Support Special Ops	3,771	0
Support Maritime Component	113	0
Killbox Interdiction/Close Air Support DMPIs**	0	15,592
Totals	25,240	19,898
* Fixed targets only for this mission area. Mobile targets included in last row. ** Spec. Ops, Maritime and mobile targets in support of Land Component.		

Table 5-4: Close air support in OIF.

CAS resources are allocated based on both pre-planned and immediate requests. **Pre-planned** requests include submissions for scheduled and on-call CAS. Preplanned requests are of two types: *scheduled* and *on-call*.

(1) **Scheduled** requests are based on identified targets and a desired time on target (TOT) well in advance. They offer greater opportunity for coordination and provide a greater chance that aircraft have the proper weapons load for the targets. This reduces the need for communications for final coordination.

(2) **On-call** requests anticipate the need for CAS wherein the requesting commander indicates a time frame, probable target type(s), and place. Aircraft are configured with the proper ordnance for anticipated targets and are on either ground or airborne alert status for a specified period of time.

Immediate requests arise from situations that develop once the battle is joined. Because immediate requests respond to developments on a dynamic battlefield, detailed coordination and preplanning of tailored ordnance loads is precluded. If on-call CAS is unavailable, a request may be made to divert a preplanned CAS mission.

Figure 5-2 illustrates the complexity of the connectivity required to plan, coordinate and execute Navy/Marine Corps CAS.[9] Due to the dynamic nature of the battlespace and the rapid pace of maneuver force movements, recent conflicts have witnessed a substantial increase in immediate requests for CAS. The challenge is to streamline and standardize CAS planning, coordination and execution across the Services to reduce timelines for retasking CAS in response to immediate requests. In addition, a further challenge is to extend the transformation discussed above to include CAS and fires into a single joint maneuver support system.

[9] This degree of complexity is not unique to the Navy and Marines – this figure was chosen to be representative.

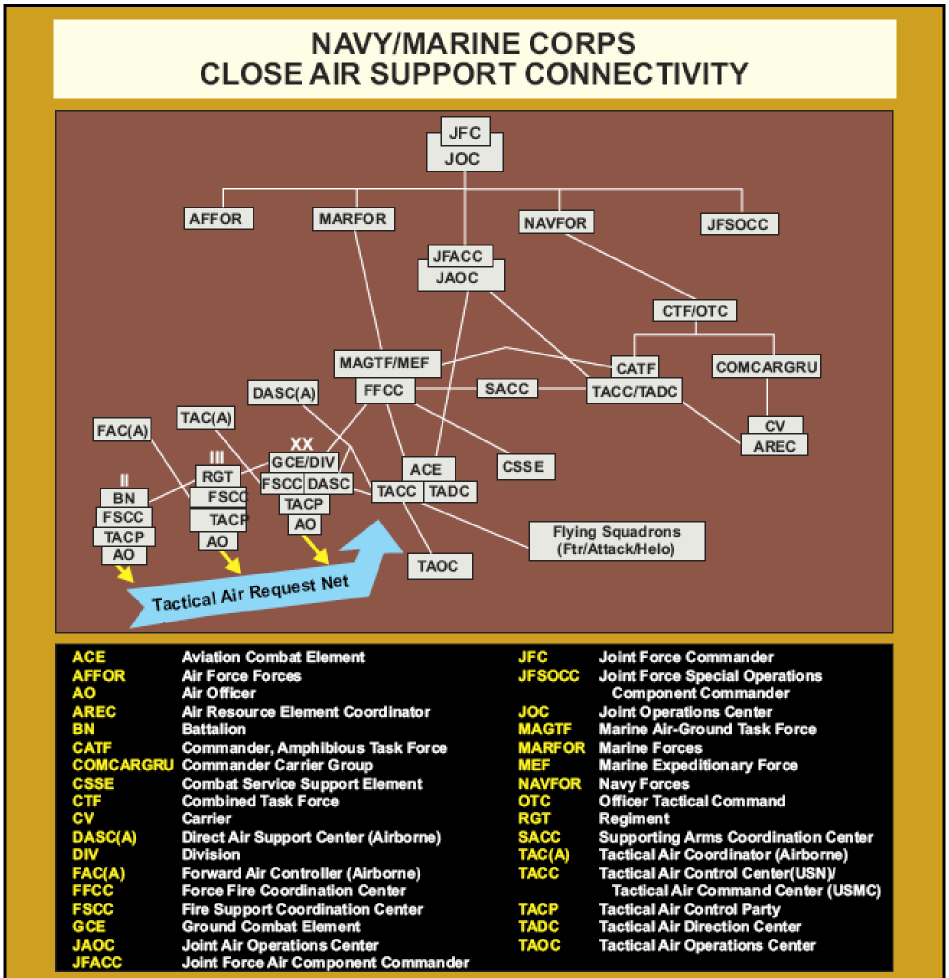

Figure II-6. Navy/Marine Corps Close Air Support Connectivity

Figure 5-2: Navy/Marine Corps close air support connectivity (JP 3-09.3).

5.4 Control/Coordination Measures

The following is an excerpt from Joint Pub 3-09:

> *An FSCL (fire support coordination line) is established and adjusted by the appropriate land or amphibious force commanders within their boundaries in consultation with superior, subordinate, supporting, and affected commanders. If possible, the FSCL should follow well-defined terrain features to assist identification from the air. In amphibious operations the FSCL is normally established by the CLF after coordination with the CATF. Changes to the FSCL require notification of all affected forces within the AO and must allow sufficient time for these forces and/or components to incorporate the FSCL change.* ***Generally 6 hours is adequate in order to coordinate an FSCL change.***

Fire support and airspace coordination/control measures are key to ensuring the safe and efficient execution of fires. Though United States Message Text Format (USMFT)

message formats support descriptions of these measures, there is currently no joint technical architecture that defines a rich internal representation and associated machine-to-machine exchange of coordination/control lines/measures. This representation should not only include the geospatial and temporal constraints embodied in these measures but also why they were established and who established them. As illustrated in Figure 5-3 below, these measures can be quite complex. The ability to rapidly redefine these measures rapidly in response to events is becoming increasingly important, as both the tempo and the distributed nature of operations increase. Effective joint decision support tools for integrated fires will require such a representation and mechanisms for rapid electronic exchange and understanding.

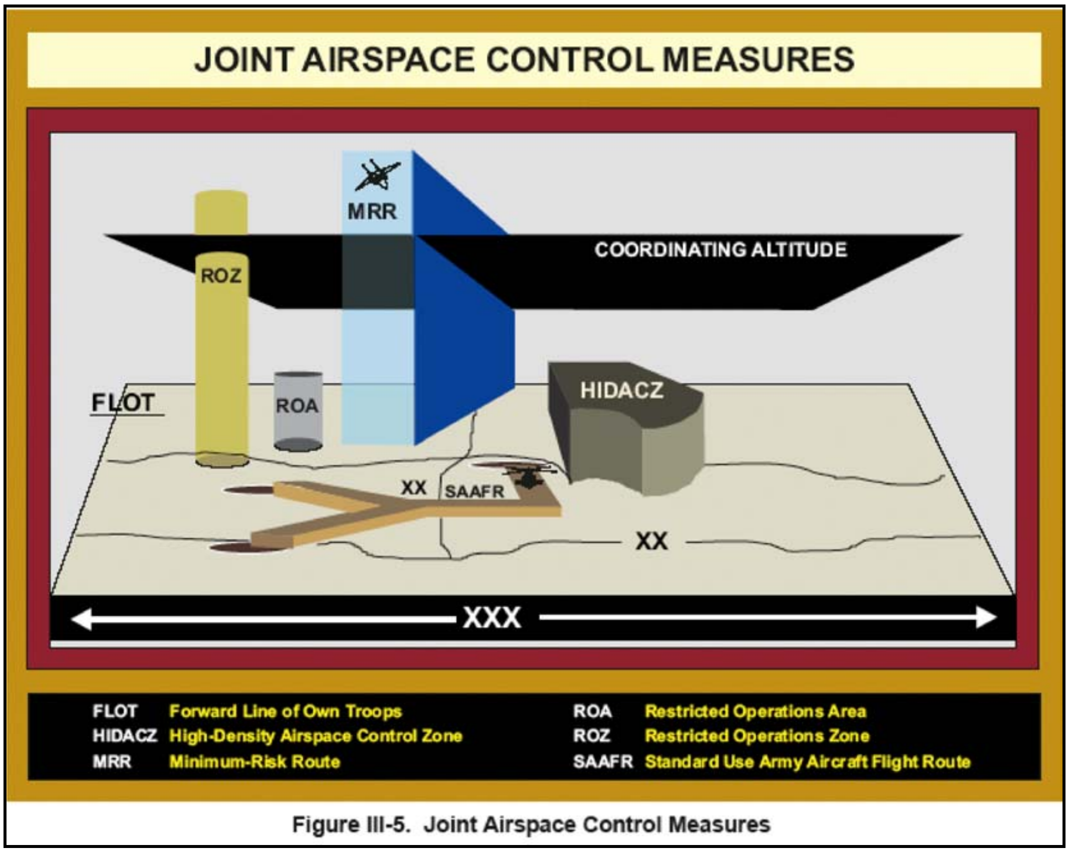

Figure 5-3: Joint airspace control measures (JP 3-09.3).

We highlighted the phrase "*Generally 6 hours is adequate in order to coordinate an FSCL change*" in the excerpt from Joint Pub 3-09 (above) to emphasize the disconnect between the expected timelines for changing coordination/control measures based on current doctrine and the pace of maneuver in recent conflicts. For instance, in OIF the management of fire support coordination lines (FSCLs) proved particularly noteworthy in this regard. The advance to Baghdad was so fast that the Army overran an established FSCL within an hour after it was established. Because the process of "moving" the line took 8 to 10 hours, air strike operations forward of the line had were impeded until it was "moved." After finding that this same situation occurred several days in a row, they moved the line far to the north. As a result, planned air strikes were precluded over an extensive region. The challenge is to capitalize on the realized improvements in BFT and

improved communications to update the procedures for creating, updating, and distributing control and coordination measures to ensure safe but rapidly changing battlefield operations.

5.5 Common Targeting Picture

To enable improved C^2 decision-making for joint fire support, a need exists for more detailed information about each target and about its associated effect than may be available in, for instance, the SIGP (single integrated ground picture) or the MIDB (military intelligence database). To enhance the timeliness of decision-making, this information must be captured in a standard format that is accessible both machine-to-machine and to operators. To increase the likelihood that these technical standards will be universally adhered to, the so-called MDA approach to information system development described in Section 5.2 should be employed.

We outline here the types of information that are desired to support improved decision-making; however, we realize that for any given target, the entire set of this information may not be available. Common Targeting Picture (CTP) contains information required to support {sensor-weapon-target-effect} decision-making. In addition, the CTP is more than simply a database in that it is a spatially oriented repository (rather than target-ID oriented) that supports decision-making to coordinate use of sensors to build up a picture and fuse data from diverse sensors for accurate grid-locking. Furthermore. it represents the foundation for a standard/joint digital target folder.

The CTP should contain the following attributes for each target:

1. Links to desired effect, objectives and outcomes including target value/prioritization inherited from desired effect and information about who nominated the effect/target and why;
2. Maneuver-related considerations such as minimum blue force-target separation;
3. Constraints relating to non-combatant casualties, hazmat, nearby facilities and unexploded ordnance;
4. Importance and timeliness of BDA including any explicit requirement for actual rather than probabilistic BDA and an indication of the potential cost to operations of making a BDA decision error; and
5. Characterization of target rate uncertainty in target state including target type classification ideally characterized by probability mass functions (PMFs); mean and covariance of target position and velocity; status relating to degree of target damage or destruction (ideally as a PMF); and finally the history of observations (which sensors or sensor types and when) that have been accumulated.

5.6 OIF 3rd Infantry Division Lessons Learned

The following excerpts from the Army 3rd Infantry Division's (3ID) report on Operation Iraqi Freedom lessons learned[10] reinforce the observations summarized above with respect to the shortcomings of current approaches to planning and execution and control and coordination measures for fire support operations.

Command and Control: Planning and Execution

- The battle staff planning cell should contain a maneuver planner, intelligence planner, logistics planner, and fires planner
- The division must have the capability to plan division level fires while in constant, rapid offensive operations
- We must consider the use of all munitions available to the maneuver commander.
- Targetable data and reporting throughout the levels of command need continuous refinement and training.
- The Army needs to develop and purchase communications platforms that meet requirements for voice and data communications, working over extremely long distances, while on the move.
- The Army needs to develop standardized digital systems across the force.

Control Measures

- Coordination at all levels is required for the placement of restrictive measures and units within all battlespace.
- Movement of permissive measures requires thorough coordination with all elements, to include the movement of the fire support coordination lines (FSCL) based on the role of the maneuver advance.
- A division forward boundary (DFB) is necessary to further delineate the battlespace. Worthy of consideration is adding the battlefield coordination line (BCL) to Army fire support doctrine.
- Opening and closing CAS kill boxes requires improved planning and coordination.
- The division must ensure that new tactics, techniques, and procedures (TTPs) for deconflicting airspace during offensive operations are captured and trained.
- It is necessary to identify land suitable for field artillery units and establish position area hazards (PAHs)/position artillery areas (PAAs) so air coordination measures can be developed around them.

[10] http://www.globalsecurity.org/military/ops/oif-lessons-learned.htm: *Third Infantry Division (Mechanized) After Action Report Operation Iraqi Freedom* U.S. Army July 2003

5.7 Recommendations

Joint Integrated Fire Support System (JIFSS)

A truly *joint* and *integrated* fire support system will employ a command and control approach that ensures that the best available target acquisition, attack and BDA resources are made available across the Services, to achieve the maneuver commander's desired effects and purpose, blurring the distinction among strike, fires, and close air support. In addressing the maneuver commander's desired effects, these decision-support tools will enable nearly continuous updates to dynamic fire support and airspace coordination/control measures to maximize both the safety of friendly forces and their flexible use of the entire battlespace. As illustrated in Figure 5-4, such a system will have service-based components that are much more tightly integrated than in today's joint fire support.

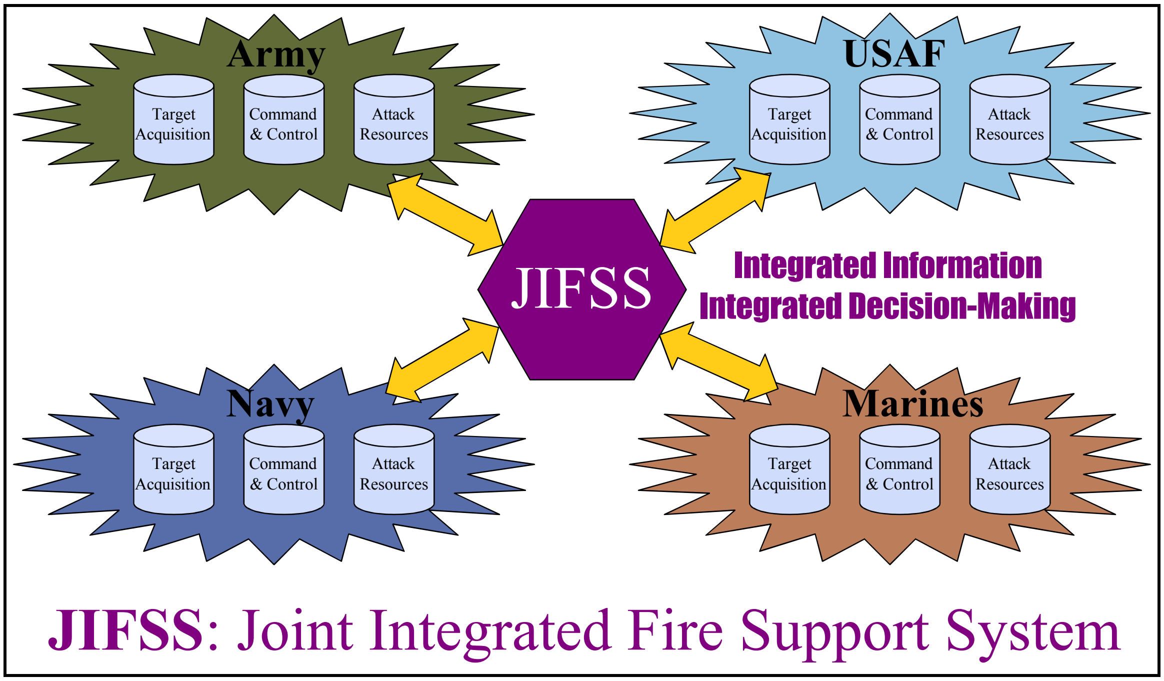

**Figure 5-4: Achieving joint fires of the future—
an integrated approach to joint fire support.**

The next sections discuss recommendations regarding (a) decision-support, (b) implementation, and (c) test and integration of the Joint Integrated Fires Support System (JIFSS). The last section summarizes the recommendations.

Decision Support

Figure 5-4 illustrates the tighter coupling of decision-making and information sharing that the recommended JIFSS will enable. Note that liaison functions will be maintained, but their effectiveness is enhanced substantially by improved functional integration.

Here we discuss the recommended improvements in Integrated Fire Support Decision-Making for allocating, scheduling and employing sensing and shooting (targeting

and fires) resources; for dynamic control and coordination measures that enable a more fluid battlespace when fires supports agile maneuvers; and for an enhanced suite of information regarding targets that will enable these improvements in decision-making.

Figure 5-6a depicts the familiar elements of the targeting cycle while emphasizing that the decisions regarding choice of assets for executing these elements ought to be tightly coupled. The recommended JIFSS decision support system will account for this coupling while not limiting the choice of assets to a single service or level of echelon within a service. The decisions will be made to optimize the components of effectiveness as outlined in Figure 5-6b. The weightings among these components are determined as a function of the commander's intent and the operational situation.

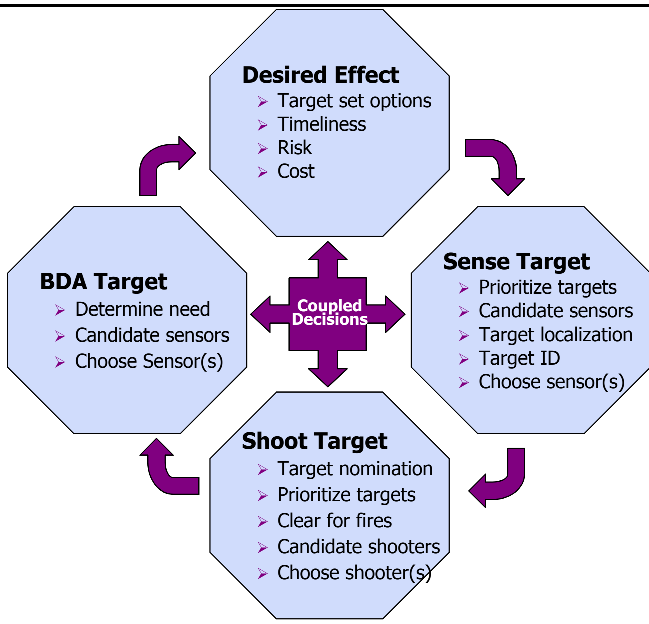

Figure 5-6a Coupled Decision-Making: Sensing, shooting and assessing decisions are coupled for a given desired target/effect.

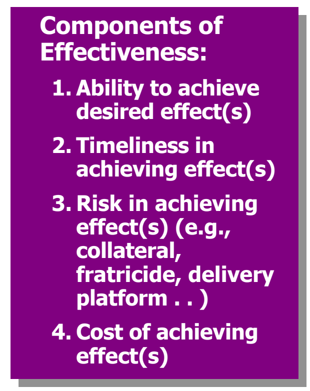

Figure 5-6b Each of these components of effectiveness should be considered in allocating and executing Joint Fires

Inputs

The JIFSS decision-support tools that will enable more effective planning and execution of joint fire support require a richer and timelier set of inputs than today's approach. These inputs include the following:

1. Improved ability to capture the maneuver commander's desired effect and associated purpose;
2. Improved target description/status (see Common Targeting Picture discussion below);
3. Improved models of {sensor-target-weapon} effectiveness;
4. Improved firing policies/strategies consistent with selected sensors, weapons, and knowledge of target status;
5. Extension of blue-force tracking to include red and gray; and

6. Improved knowledge of the current state and tasking of blue targeting and fires assets (air, land, and sea).

Common Targeting Picture

To support improved {sensor-shooter-target-effect} decision-making and situation awareness for Integrated Joint Fire Support we recommend that both the ground and air components (SIGP and Single Integrated Air Picture (SIAP)) of the Family of Interoperable Operating Pictures (FIOP) be augmented to include standards for a much richer set of information for elements of the battlespace that are either identified as targets or have the potential to be nominated as targets. We refer to this augmented subset of the FIOP as the Common Targeting Picture (CTP). In addition we recommend that processes and procedures be developed and employed to improve the ability to create, update and disseminate the CTP. Finally, we note that the CTP can be envisioned as basis for a standard joint digital target folder for air, ground and maritime targets.

Dynamic Asset Assignment/Command Relationships

Although Figures 5-5 and 5-6a may seem to indicate that the JIFSS is based on a completely centralized approach to planning and execution; however, this is not the case. When decisions are time-critical and/or when the state of the digital communications network precludes timely sharing of the input information described above, the decision-support tools must be able to function in a distributed manner on less than complete information and must consider targeting and fires assets either under local control or those which can be negotiated locally.

One approach to improving the timely availability of assets is by dynamic and anticipatory cross-service scheduling and assigning of sensing and shooting assets. This is analogous to the approach currently employed for joint close air support (CAS). When prior information is insufficient to pre-assign assets, JIFSS must provide decision-support aid in agilely reassigning assets as needed. This is analogous to the approach currently taken in assigning aircraft for time-critical-targets.

Another aspect of the management of resources that JIFSS must support is ensuring the persistent availability of fires. Indeed, field artillery batteries must occasionally both reload and perform counter-battery self-protection maneuvers – during which times they are unavailable to provide fires. The JIFSS must support cross-battery coordination of operations and location of batteries that ensures availability of persistent fires over time. We anticipate that novel battery employment strategies will be enabled in the future by the extended ranges of precision munitions.

Dynamic Fire Support Control/Coordination Measures

The use of fire control and coordination measures has evolved over time to ensure safety and to preclude duplication of fires. We recommend that the approach to the development, dissemination and updating of these measures be reviewed to identify (a) how they can be made less complex and (b) how they can be developed and employed in a more timely fashion. We recommend that JIFSS provide decision-support for dynamic fire support coordination measures developed to accommodate the non-linear battlespace and higher tempo of operations that have been observed in recent conflicts and that take advantage of longer-range precision munitions and improved Blue Force Tracking. This

will require a new suite of tools that simultaneously address airspace and fires deconfliction and that allow for rolling up measures when they become obsolete as the fight progresses. We recommend that new standard joint digital representations be developed for these measures that are specifically designed to support their rapid updating via automated reasoning and machine-to-machine dissemination.

JIFSS Implementation: A Model-Driven Architecture (MDA) Approach

The design, development, testing and integration of the Joint Integrated Fire Support System (JIFSS) called for in this report is an extremely challenging proposition. Many independently developed and managed systems must be modified to achieve the required functionality, and the resulting system of systems (i.e., JIFSS) must be tested to verify its correct dynamic operation.

The conventional approach to implementing a large-scale system such as JIFSS would be to (1) develop a specification of the interface to which each system component must adhere and (2) specify the added functionality that each system component must implement (e.g., for making weapon-target pairing decisions and exchanging JIFSS messages). This specification would consist of text and diagrams, including perhaps models specified in the industry standard Universal Modeling Language (UML). The development of such a specification is itself an extremely challenging proposition and history has shown that employing the traditional approach inevitability leads to ambiguities and errors. Even if the specification were perfect, its implementation by system developers would contain errors. These errors are only discovered in expensive, large-scale testing. Moreover, even if each component developer got everything right the first time, the implementation would be extremely expensive as each system component would ultimately redundantly implement similar functionality. Finally, evolution of the system of systems would be complex: any change to the interface or functionality specification would require modifications to all the individual system components.

The problems associated with implementing distributed systems are not peculiar to JIFSS, but are central to enterprise integration in large scale commercial as well as military systems (often referred to as network-centric systems in the latter context). Under the auspices of the Object Modeling Group (OMG), the industry standards organization that developed UML, an approach has been developed to address these problems.

The OMG approach, referred to as the Model-Driven Architecture (MDA) approach, replaces the development of a paper specification for distributed systems of systems with the development of a so-called Platform-Independent Model (PIM).[11] The PIM is specified in executable UML (xUML), an extension of UML that is sufficiently rigorous that a so-called Platform-Specific Model (PSM) can be unambiguously generated from the PIM. The PSM is the PIM functionality combined with platform-specific interfaces and services. Finally, the PSM is used to generate a Platform-Specific Implementation (PSI). The PIM is provided to the component developers instead of a paper specification and their job is to develop PSM and PSI for their computing platform or

[11] Note that platform here refers to a computing platform (i.e., a specific configuration of hardware, operating systems, and middleware, not an aircraft, land vehicle, or ship).

platforms. This task can be heavily automated and supported by commercially available tools.

The MDA approach has a number of advantages for the implementation of JIFSS and similar network-centric systems of systems. First, the functionality is developed only once, in the PIM, reducing costs and the potential for inconsistent implementations. Second, the PIM can be used to test the functionality of the distributed system of systems prior to its implementation. This is accomplished by generating a PSM or PSMs for the computing platform or platforms of a simulation environment. Errors in the PIM can be found by simulation testing prior to implementation and testing with the real systems.

Third, changes in the system of systems, whether due to errors, advances in algorithm technology, or increases in functionality from a spiral development effort, can be readily accommodated by changes to the PIM. The correctness of these changes can be verified by simulation prior to dissemination of the revised PIM to the individual system developers. Since the system developers have a process for translating from the PIM to the PSI, the required changes to their systems can be made more quickly and at less cost, with less potential for error.

Fourth, the use of a PIM isolates the system of systems from changes in computing platform technology. If, for example, an individual system developer wishes to move from a proprietary architecture to an open architecture, the developer needs simply to update his process for generating a PSI from the PIM.

In summary, MDA isolates the functionality of the system from the implementation technology. The PIM and not the executable code becomes the fundamental configuration item. The MDA approach enables the testing of system interactions and performance at the architecture design stage, prior to implementation. It facilitates using code generators to automatically develop, evolve, and maintain enterprise-scale distributed applications.

While the MDA approach appears to be the most promising for the development of large-scale, network-centric applications such as JIFSS, several cautionary notes are necessary. First, while it has been successfully employed in several large-scale commercial and military systems (notably, the F-16 mission software developed by Lockheed Martin) and is being used in the SIAP program for an application similar to JIFSS, the MDA technology base is not fully mature. For example, standards have not matured to the point where different vendors' tools are fully inter-operable. Second, the MDA approach requires a significant up front investment in time and resources before its benefits can be seen. The initial focus is on the development of the PIM so that there is an extended design stage in which not much code is generated and progress may not be very visible and easily tracked using traditional metrics. Despite these caveats, we recommend that DoD employ and devote resources to both maturing the technology and gaining experience with the MDA approach and that the approach be used for the development of JIFSS and similar DoD large-scale system-of-systems.

TTPs, Experimentation, and Training

Test, integration, training and experimentation are all elements of the development life cycle for the JIFSS. To support these elements of the life cycle, we recommend that exercises of realistic joint/coalition field exercises emphasizing integrated air, ground and maritime fire support operations be conducted. These exercises should stimulate JIFFS decision-making processes across the services and across echelons within the services.

All inputs (requests) and outputs (decisions) should be exercised to stimulate the machine-to-machine dissemination of information and the communications infrastructure required to effect that dissemination. The DoD must ensure the participation of all services and evaluate the joint process down to the level of small units requesting fires, the planning and execution of the fires and the evaluation of the effects of the fires.

In addition to supporting test, integration and training, exercises should be designed to experiment and evaluate the development of novel joint tactics, techniques and procedures (TTPs) enabled by more tightly integrated planning and execution of maneuver and joint fires. We recommend that existing simulation capabilities be enhanced to support the broad scope of these joint exercises.

Finally we recognize that the Joint Battle Management Command and Control (JBMC^2) Roadmap is the key DoD management plan that has been designed to ensure interoperability of C^2 systems involved in Joint Fires. The scope of that plan includes: Integrated fires, Joint Close Air Support, Joint Ground Maneuvering and Time Sensitive Targeting as well as Air and Missile Defense. A plan for experimentation, simulation and exercises under the direction of JFCOM are an integral part of the roadmap and we recommend that the roadmap be followed and augmented to include the exercises required for test, integration, evaluation, experimentation and training for the JIFSS.

5.8 Summary of Recommendations

1. USD(AT&L) and ASD(NII) should work toward the development of a tactical Joint Integrated Fire Support Systems (JIFSS). The JIFSS will be a truly joint decision-support system for allocating, scheduling, assigning, and executing all sensing and shooting activities for joint fire support. This includes coordinating JCAS decisions with ground and sea-based fires and targeting. The JIFSS will also be based on standardized dynamic fire support coordination/control measures that accommodate longer-range weapons and higher tempo operations. Finally, to enable improved and more timely fires and targeting decision-making provided by the JIFSS, we recommend augmenting the current family of common operational pictures (FIOPS) with richer target information embodied in the Common Targeting Picture (CTP).
2. USD(AT&L) and ASD(NII) should employ the Model-Driven Architecture (MDA) development approach for designing the JIFSS architecture and in implementing its component systems. The MDA approach ensures adherence to standards across the components and has been shown to substantially reduce costs in the development of large-scale systems-of-systems.
3. USD(AT&L) and ASD(NII) should continue to follow the Joint Battle Management and Control (JBMC^2) roadmap to achieve the interoperability required for JIFSS. We recommend augmentation of the roadmap to ensure a phased transition from currently planned service systems to the future JIFSS.
4. JFCOM should conduct joint exercises and develop simulation capabilities to support integration and test of the JIFSS, as well as joint training and joint development and evaluation of novel tactics enabled by integrated planning and execution of joint fires and maneuver.

REPORT APPENDICES A-F

APPENDIX A: TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

June 3, 2003

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board Task Force on Integrated Fire Support in the Battlespace

You are requested to form a Defense Science Board (DSB) Task Force on Integrated Fire Support in the Battlespace.

The 2001 Precision Targeting Summer Study laid out a methodology for thinking about the problem, assessing our current capabilities, and making detailed recommendations for improvement. Unfortunately, the scope of the study did not address the shorter range ground and sea launched weapons systems characterized by ERGM and XCALIBER. These and other components of in-theater systems operate under the control of the on scene commander and are designed to provide fires, both organic and inorganic, in support of fielded forces. These systems must be fully integrated with all the tools the on scene commander brings to the battlespace. Failure to integrate fire support in the battlespace unnecessarily places forces at risk and may mean mission failure.

The Task Force should apply the methodology developed in the 2001 Precision Targeting Summer Study to these and other tactical weapon systems and to broadly develop the system of systems required to provide truly integrated fire support. The Task Force should address the following:

- Assess the adequacy of current and proposed munitions with respect to speed, accuracy, lethality, cost, etc. to meet the spectrum of threats;
- Assess Intelligence Surveillance and Reconnaissance (ISR) techniques and mechanisms to meet the needs of tactical and operational battlefield forces with a view towards persistence, survivability, accuracy, cost, bandwidth requirements, etc. Ensure the ISR capabilities can provide timely battle damage assessment and conduct Blue force tracking;
- Assess the adequacy of battlefield command and control and integration techniques for tactical, operational, and strategic forces operating on the battlefield.

- Assess the current impediments to a fully integrated Air, Land and Sea fire support. Review and recommend future options which could be made available to the on scene commander to provide an integrated fire support capability.

- Assess the need for predictive engagement tools and derived intelligence products to guide the battlefield commander in use of forces to shape the outcome to the desired effect.

The above study should be performed in the context of the newly evolving acquisition and requirements process that focuses on warfighting capabilities and conducted with the active participation of Joint Forces Command.

The Task Force should also revisit the recommendations from the 2001 Precision Targeting Summer Study and revalidate and follow up those recommendations that have not been implemented.

The Task Force should also assess the impact of identified technologies on joint warfighting capability and interoperability.

The Study will be co-sponsored by me as the USD(AT&L), Commander, Joint Forces Command, Director, Defense Advanced Research Projects Agency, and the Director, Defense Systems. Mr Bob Nesbit and Mr. Vince Vitto will serve as co-chairmen of the Task Force. Ms. Robin Quinlan, Defense Systems, will serve as Executive Secretary; and CDR Dave Waugh, USN, will serve as the Defense Science Board Secretariat representative.

The Task Force will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.

(Acting)

APPENDIX B:

PANEL MEMBERS, ADVISORS & SUPPORT STAFF

Chairmen	
Mr. Robert Nesbit	MITRE Corporation
Mr. Vince Vitto	C.S. Draper Laboratory
Executive Secretary	
Ms. Robin Quinlan	Assistant Director, Force Integration USD(AT&L)
Members	
Dr. Milt Adams	C.S. Draper Laboratory
Dr. Alan Berman	ARL Pennsylvania State University
Dr. Webster Dove	BaE Systems
Mr. Everett Greinke	GMD Solutions
Dr. Daniel Held	Northrop Grumman
Mr. Bruce Johnson	MITRE Corporation
Dr. David Kalbaugh	The Johns Hopkins University Applied Physics Lab
Hon. Noel Longuemare	Private Consultant
GEN (Ret.) David Maddox	Private Consultant
Dr. Joseph Markowitz	Private Consultant
Mr. John Matsumura	RAND Corporation
Mr. Thomas McNamara	The Charles Stark Draper Lab
LTG Randall (Ret.) Rigby	Sandia Laboratories
Dr. Nils Sandell	ALPHATECH, Inc.
Mr. Robert Stein	Private Consultant
Government Advisors	
COL (Ret.) John Bolger	U.S. Army
COL Paul Burke	U.S. SOCOM
CDR Calvin Craig	Dep. Chief of Naval Ops Assess. Div. OPNAV N812E
Mr. Jon Estridge	NGA
Lt. Col. Kirk Hymes	Expeditionary Force Development Center
Mr. Doug Richardson	U.S. SOCOM
Major John Sweeney	U.S. SOCOM
CDR Jesse Wilson	J-8
Support	
Mr. William Beasley	USD (AT&L)
Ms. Nicole Coene	SAIC
Mr. Mark Mateski	SAIC
DSB Secretariat	
CDR David Waugh	Defense Science Board USD(AT&L)

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APPENDIX C:

BRIEFER LIST (OCTOBER 2003-APRIL 2004)

Date/Briefer	Organization	Topic
8 Oct. 2003		
COL Chuck Waggoner	U.S. Army	Integrated Fire Support
COL Mike Cannon	U.S. Army	Future Combat Systems (FCS)
Dr. Gerardo Melendez	PM Networks	FCS C^4ISR Overview
COL Lance Carroll	U.S. Army	Single Integrated Ground Picture
COL Walt Fountain	U.S. Army	- Distributed Common Ground System-Army - Prophet - Aerial Common Sensor (ACS)
COL Kent Woods	U.S. Army	- Army Tactical Command and Control Systems, - Force XXI Battle Command and Control, - Global Broadcast Services
9 Oct. 2003		
COL Ricky Rife	G8/FDV	<u>Army Direct Fire Systems:</u> - Air-to-Ground Missiles
COL Mike Harrison	G8/FDD	- Close Ground Combat Missile System - Precision Guided Mortar Munitions - Mid-Range Munitions (MRM)
COL Carlos Rodriguez	G8/FDS	<u>NLOS Systems:</u> - Cannon Transformation: - Paladin, LWISS Howitzer, Non line-of-site Cannon-C (NLOS-C) - Multiple Launch Rocket System (MLRS) Transformation: - MLRS Family of Munitions, Launcher Evolution, Himars, - GMLRS, ATACMS Family of Munitions, NLOS-LS
5 Nov. 2003		
CDR Jesse Wilson	J8	Joint Capabilities Integration and Development System
BG Charles Patton	-	Integrated Fired Introduction
Col Steven Hogg	EWTGPAC	Naval Fire Support
Dr. Michael Bell	OPNAV N61	FORCENet Overview
CDR David Foley	OPNAV N20	ISR Architecture

Date/Briefer	Organization	Topic
CAPT James Huck	OPNAV N61	- Joint Fires Network (JFN) - Global Command and Control System (GCCS)
LCDR Bill Jones	OPNAV N20	Joint Targeting Toolbox
LtCol Jeffrey Seng	OPNAV N75/76	Surface Fires Concept Operations (CONOPS) and Supporting Arms Co-ordination Center-Automation (SACC-A)
6 Nov. 2003		
- CDR Charles Marx - Ms. Dixon	OPNAV N76	DD(X) Program and the Advanced Gun System (AGS)
Mr. Brian Baudler	NAVSEA	5"/62 and ERGM/ANSR
Mr. Chris Ange	NAVSEA	Advanced Gun System (AGS)
Mr. Fred Beach	NAVSEA PMS405	Electromagnetic Rail Gun
- CDR Hal Murdoch - CDR James Dalberg	OPNAV N78	F-18 E/F and Joint Strike Fighter (JSF)
LtCol Christopher St. Gerorge	OPNAV N78	Aviation Munitions
- LtCol Kirk Hymes - Col Robert Schmidle	U.S.MC	Marine Corps Integrated Fire Support CONOPS and Transformation Efforts
Maj Fred Woodaman	U.S.MC	Operation Enduring Freedom and Operation Iraqi Freedom (lessons learned)
10 Dec. 2003		
Ms. Robin Quinlan	AT&L	Acquisition Process as it relates to JCID
Mr. Dan Gonzales	AT&L	Joint Battle Management Command & Control (JBMC^2) Roadmap
LtCol Scott Sanborn	U.S.D(I)	Distributed Common Ground System (DCGS)
LtCol Judy Chizek	U.S.AF	DCGS Integration Backbone (DIB)
CAPT Al Thomas	U.S. Navy	Joint Fire Networks (JFN) / Tactical Exploitation System (TES)
Mr. Bill Beasley	AT&L	- Draft of Memorandum of Agreement for JCAS - Discussion on Future DSB Task Force Meetings - Recent Joint Munitions Effectiveness Initiatives
Mr. Dyke Weatherington	-	UAV Updates

Date/Briefer	Organization	Topic
11 Dec. 2003		
Mr. Scott Robinson	NGA	Future Warfare Systems Office NIMA Support to Future Combat Systems
Ms. Michele Williams	NGA	Office of Geospatial Intelligence Management
Mr. George Krakie	NGA	Gridlock Update
Mr. Rob Thomas	NGA	Geopositioning Study (GPS AII Update)
Mr. John Tuley	NGA	- Office of Precision Targeting/Navigation - Airborne Tgt Cell
Mr. Gray Thompson	DIA	MIDB Status Issues
14 Jan. 2004		
BG Bob Durbin	U.S. Army	Introduction
COL(P) Ben Allen	U.S. Army	Army Maneuver and Fire Support
Col Bob Koster	U.S. Army	Army Maneuver and Fire Support
Mr. Ray Carnes	U.S. Army	Future Combat Systems (FCS)
Mr. Tim Puckett	U.S. Army	Future Combat Systems (FCS)
Mr. John Wellman	U.S. JFCOM J8	Joint Forces Command's Efforts
Col Peter Hayward	U.S. JFCOM J8	Joint Close Air Support (JCAS)
15 Jan. 2004		
LtCol Kirk Hymes	U.S. MC	Fire Support Planning
Maj Brian Annichiarico	U.S. MC	Marine Corps Close-Air Support Overview
- Mr. Joseph H. Francis - CAPT Al Thomas	U.S. Navy	- JACKKNIFE FY05 Act D Proposal - Joint Fires Network (JFN)
Mr. Duane Schattle	U.S. JFCOM J9	Joint Urban Operations
Maj John Sweeney	SOCOM	SOCOM Fire Support
11 Feb. 2004		
Mr. Bob Polutchko	C.S. Draper Lab	Precision Guidance (GPS Internal Guidance Systems)
Dr. Erwin Atzinger	JTCG/ME	Joint Munitions Effectiveness
Mr. Robert Chandler		Joint Munitions Effectiveness
Mr. Bob Nesbit	MITRE Corp.	DSB Unmanned Aerial Vehicles (UAV) Summary
BG Robert Schmidle	USMC	USMC Perspective on Integrated Fires
Mr. Bob Stein	-	Seekers/Data Links
12 Feb. 2004		
Dr. Dave Honey	DARPA	ATO Overview/Emerging Communications Concepts
Dr. George Duchak	DARPA	Adaptive C^4ISR Communications Node

Date/Briefer	Organization	Topic
Dr. Reggie Brothers	DARPA	CDMA on the Battlefield
Dr. Jim Freebersyser	DARPA	- Multiple-Input, Multiple-Output Communications - FCS Communications
Dr. Brad Tousley	DARPA	NETFIRES
Dr. Art Morrish	DARPA	TTO Overview/Emerging Weapons Concepts
Dr. Steve Waller	DARPA	Tactical Network Technology
Dr. Bob Tenney	DARPA	- Dynamic Tactical Targeting - Joint Air/Ground Battle Management - IXO Overview/Emerging C^4ISR Concepts
17 March 2004		
Mr. John Blomquist	JTCG/ME	Joint Munitions Effectiveness – Presentation of Special Calculation Results
Mr. Robert Chandler	JTCG/ME	
Mr. Bill Clay	JTCG/ME	
21 April 2004		
COL Lance Carroll	U.S. Army	Combat Identification Initiatives
Mr. Clay Davis	OUSD(AT&L)/Air Warfare	Land Attack
Ms. Diane Wright	OUSD(AT&L)/Air Warfare	

APPENDIX D:

JMEM ANALYSIS

The following spreadsheets contain the results of several JMEM analyses that we conducted to arrive at the results presented in Chapter 3 of this report. These analyses calculated the number of rounds required to provide .1, .3 and .8 fractional damage (FD) at various TLEs using three different munitions against three different types of targets. The three munitions used were an unguided unitary round (combined with a forward observer), a guided unitary round, and a guided discriminatory round. The specific target classes were a truck (soft target), armored personnel carrier (medium target), and a tank (hard target). With the exception of the armored personnel carrier, which is provided for reference only, these attributes reflect the same variables mentioned earlier.

The parameters used for the rounds are shown with their accuracy for 2/3 maximum range and 1/2 hour met staleness. The accuracy consists of precision and mean point of impact (MPI) errors in range (R) and deflection (D) that equate with those in Table D-1 of this report. Also shown is the angle of fall (AOF) for the rounds at these ranges which translate into warhead lethality performance for weapons so equipped.

We have provided a point target and an area target case for each target class. The point target is one vehicle. To calculate the effectiveness of the weapon against this target, single rounds were shot until the desired effect was achieved. This represents the examples used previously in Section 3.4 of this report.

The area target case was not discussed earlier in this report and is again provided for reference only. In this case, we assumed the following: a battery of six guns shoots at a target area, and the target consists of six vehicles. Therefore increments of six rounds were shot, one from each gun, until the desired effectiveness was achieved. As a result, all calculations are a factor of six rounds.

Aiming policy for the area targets was also done two ways for the unguided unitary round. The blue shaded unguided unitary shows the results of distributed aim points. The distributed aiming policy means that the aim points were distributed evenly about the target area.

The unshaded unguided unitary used only the precision aiming policy (this also applies to the guided unitary and the guided discriminatory table entries). The precision aiming policy means that the six aim points were aimed directly on each of the vehicles in the target area. The aim points and targeted areas are noted on the spreadsheet.

The guided discriminatory concept round assumes laser designation. It is assumed that the target element is laser designated appropriately to guide the round. It is important to note that TLE will not affect the effects until this error becomes larger than the radius of the footprint. The level of delivery error played assumes the round is delivered close enough to the aim point so that the onboard seeker can acquire the laser energy and the round guides to the aim point. A footprint radius of 100 meters was assumed based on similar munitions of this type.

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TRUCK - POINT TARGET

Common Parameters:

Range	Rounds Per Volley	MET Staleness	Kill	Aimpoint
2/3 MAX	1	1/2 hr.	M	(0,0)

Munition	Precision (m)		MPI (m)				Rounds required for each TLE in meters											
							0	2	5	10	15	20	25	30	35	40	45	50
	R	D	R	D	AOF	FD												
Unguided Unitary	57	15	112	35	30	0.1	5	5	5	5	5	5	5	6	6	6	6	6
						0.3	17	17	17	17	17	17	19	21	22	24	26	30
						0.8	520	535	535	593	653	783	868	>1000	>1000	>1000	>1000	>1000
Guided Unitary	5	5	6	6	75	0.1	1	1	1	1	1	1	1	1	1	1	2	3
						0.3	1	1	1	1	1	2	2	3	4	7	13	24
						0.8	2	2	2	3	6	15	61	331	>1000	>1000	>1000	>1000
* Guided Discriminatory	1	1	0	0	N/A	0.1	1	1	1	1	1	1	1	1	1	1	1	1
						0.3	1	1	1	1	1	1	1	1	1	1	1	1
						0.8	1	1	1	1	1	1	1	1	1	1	1	1

* Assumes laser designator on target

Table D-1

TRUCK - AREA TARGET

Common Parameters:

Range	Rounds Per Volley	MET Staleness	Kill	Aimpoints	Target Area
2/3 MAX	6	1/2 hr.	M	(See below)	300m x 100m

Munition	Precision (m) R	Precision (m) D	MPI (m) R	MPI (m) D	Angle of Fall	FD	Rounds required for each TLE in meters: 0	2	5	10	15	20	25	30	35	40	45	50
Unguided Unitary						0.1	18	18	18	18	18	18	18	18	18	18	18	18
	57	15	112	35	30	0.3	54	54	54	54	60	60	60	60	60	60	60	66
						0.8	912	912	912	930	942	978	>1000	>1000	>1000	>1000	>1000	>1000
Unguided Unitary						0.1	18	18	18	18	18	18	18	18	18	18	18	18
	57	15	112	35	30	0.3	48	48	48	48	48	48	48	54	54	54	54	54
						0.8	678	678	696	708	714	738	786	834	912	990	>1000	>1000
Guided Unitary						0.1	6	6	6	6	6	6	6	6	6	6	6	6
	5	5	6	6	75	0.3	12	12	12	12	12	12	12	12	18	18	18	24
						0.8	36	36	36	36	36	48	60	72	90	126	186	294
* Guided Discriminatory						0.1	6	6	6	6	6	6	6	6	6	6	6	6
	1	1	0	0	N/A	0.3	12	12	12	12	12	12	12	12	12	12	12	12
						0.8	30	30	30	30	30	30	30	30	30	30	30	30

* Assumes laser designator on target

** Cases not run due to extensive computer time.

Precision Aimpoints (D,R):
(-125,20), (-75,-20), (-20,-40), (20,-40), (75,-20), (125,20)

Distributed Aimpoints (D,R):
(-100,25), (-100,-25), (0,25), (0,-25), (100,25), (100,-25)

Table D-2

ARMORED PERSONNEL CARRIER - POINT TARGET

Common Parameters:

Range	Rounds Per Volley	MET Staleness	Kill	Aimpoint
2/3 MAX	1	1/2 hr.	M/F	(0,0)

Munition	Precision (m)		MPI (m)		Angle of Fall	FD	Rounds required for each TLE in meters											
	R	D	R	D			0	2	5	10	15	20	25	30	35	40	45	50
Unguided Unitary	57	15	112	35	30	0.1	57	57	57	58	62	67	67	75	81	85	93	99
						0.3	278	278	281	291	309	333	372	410	474	561	666	806
						0.8	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Guided Unitary	5	5	6	6	75	0.1	1	1	1	2	3	5	9	16	30	63	155	380
						0.3	3	3	4	7	16	52	274	>1000	>1000	>1000	>1000	>1000
						0.8	17	19	34	326	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
* Guided Discriminatory	1	1	0	0	N/A	0.1	1	1	1	1	1	1	1	1	1	1	1	1
						0.3	1	1	1	1	1	1	1	1	1	1	1	1
						0.8	1	1	1	1	1	1	1	1	1	1	1	1

* Assumes laser designator on target

Table D-3

ARMORED PERSONNEL CARRIER - AREA TARGET

Common Parameters:

Range	Rounds Per Volley	MET Staleness	Kill	Aimpoints	Target Area
2/3 MAX	6	1/2 hr.	M/F	(See below)	300m x 100m

Munition	Precision (m)		MPI (m)		Angle Of Fall	FD	Rounds required for each TLE in meters											
	R	D	R	D			0	2	5	10	15	20	25	30	35	40	45	50
Unguided Unitary	57	15	112	35	30	0.1	222	222	222	222	228	240	240	240	252	258	270	282
						0.3	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
						0.8	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Unguided Unitary	57	15	112	35	30	0.1	186	186	186	192	192	192	192	198	204	204	204	216
						0.3	708	708	708	720	726	738	738	768	774	798	816	852
						0.8	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Guided Unitary	5	5	6	6	75	0.1	12	12	12	12	18	30	36	48	60	78	90	108
						0.3	24	24	30	42	72	126	222	396	696	>1000	>1000	>1000
						0.8	114	120	150	414	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
* Guided Dis-criminatory	1	1	0	0	N/A	0.1	6	6	6	6	6	6	6	6	6	6	6	6
						0.3	12	12	12	12	12	12	12	12	12	12	12	12
						0.8	36	36	36	36	36	36	36	36	36	36	36	36

* Assumes laser designator on target

Precision Aimpoints (D,R):	Distributed Aimpoints (D,R):
(-125,20), (-75,-20), (-20,-40), (20,-40), (75,-20), (125,20)	(-100,25), (-100,-25), (0,25), (0,-25), (100,25), (100,-25)

Table D-4

TANK - POINT TARGET

Common Parameters:				
Range	Rounds Per Volley	MET Staleness	Kill	Aimpoint
2/3 MAX	1	1/2 hr.	M/F	(0,0)

Munition	Precision (m) R	Precision (m) D	MPI (m) R	MPI (m) D	Angle of Fall	FD	0	2	5	10	15	20	25	30	35	40	45	50
							Rounds required for each TLE in meters											
Unguided Unitary						0.1	71	71	71	74	78	78	83	85	95	101	111	123
	57	15	112	35	30	0.3	327	327	327	347	372	397	445	502	583	676	802	967
						0.8	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Guided Unitary						0.1	1	2	2	3	4	7	13	24	49	120	321	936
	5	5	6	6	75	0.3	4	4	5	10	24	89	491	>1000	>1000	>1000	>1000	>1000
						0.8	25	28	51	635	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
* Guided Discriminatory						0.1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	0	0	N/A	0.3	1	1	1	1	1	1	1	1	1	1	1	1
						0.8	1	1	1	1	1	1	1	1	1	1	1	1

* Assumes laser designator on target

Table D-5

2/3 MAX	6	½ Hr.	M/F	(See below)	300m x 100m

Munition	Precision (m) R	Precision (m) D	MPI (m) R	MPI (m) D	Angle of Fall	FD	0	2	5	10	15	20	25	30	35	40	45	50
							Rounds required for each TLE in meters											
Unguided Unitary	57	15	112	35	30	0.1	264	264	264	264	270	282	282	288	294	306	318	330
						0.3	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
						0.8	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Unguided Unitary	57	15	112	35	30	0.1	228	228	228	228	228	234	234	240	240	240	252	252
						0.3	858	858	858	858	882	894	894	912	930	954	990	>1000
						0.8	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Guided Unitary	5	5	6	6	75	0.1	12	12	12	18	24	36	54	72	96	120	144	180
						0.3	30	30	36	60	102	204	402	816	>1000	>1000	>1000	>1000
						0.8	150	156	216	768	>1000	>1000	>1000	>1000	>1000	>1000	>1000	>1000
Guided Smart	5	5	6	6	N/A	0.1	2	2	2	2	2	2	3	3	3	3	4	4
						0.3	6	6	6	6	6	7	8	9	9	9	10	10
						0.8	28	29	30	30	36	40	42	48	54	60	64	66
* Guided Discriminatory	1	1	0	0	N/A	0.1	6	6	6	6	6	6	6	6	6	6	6	6
						0.3	12	12	12	12	12	12	12	12	12	12	12	12
						0.8	42	42	42	42	42	42	42	42	42	42	42	42

* Assumes laser designator on target

Precision Aimpoints (D,R):	Distributed Aimpoints (D,R):
(-125,20), (-75,-20), (-20,-40), (20,-40), (75,-20), (125,20)	(-100,25), (-100,-25), (0,25), (0,-25), (100,25), (100,-25)

Table D-6

APPENDIX E.

COST-TO-KILL ANALYSIS RESULTS

The following spreadsheets contain the results of the "cost-to-kill" analysis (see Chapter 3 of the main report). Cases presented include the combination or three target types (truck, APC, and tank); three fractional damage objectives (0.1, 0.3 and 0.8); three weapon types (unguided unitary, INS/GPS guided unitary, and a seeker-guided discriminatory kinetic weapon); and three transportation and support costs ($500, $750, and $1,000 per round). Results for "break-even" unit procurement costs (UPC) are provided for all cases as a function of TLE varying between 0 and 30 m.

The first row of the table contains the assumed UPC for the three weapon types. The next nine rows contain the data for the case of a truck target and a desired fractional damage of 0.1. For a TLE of 0 to 30 m (column 1), columns 2, 3, and 7 contain the JMEM numbers of unguided unitary, guided unitary, and seeker-guided discriminatory weapons required to achieve a mobility kill of the target at the desired level of fractional damage. For a transportation and support unit cost of $500, $750, and $1,000 respectively, columns 4, 5, and 6 present what the UPC of the GPS/INS weapon would have to be to break even, on a total cost-to-kill basis, with the $500 UPC unguided unitary weapon. If the break-even cost for the GPS/INS weapon is higher than the assumed $15,000 UPC, then the less expensive weapon to use is the GPS/INS. These cases are highlighted in green. A similar presentation is included in columns 8, 9, and 10 for the break-even UPC of the seeker-guided discriminatory weapon as compared to the GPS/INS unitary. Those cases in which the seeker-guided weapon is the less expensive option are highlighted in red. The first nine row case for the truck at 0.1 fractional damage is then repeated eight more times for the other combinations of three targets and three fractional damage levels.

Focusing on columns 5 and 9 (the transportation and support cost of $750 per round discussed in the main body of the report), for those cases (rows) in which no green or red costs exist, the unguided unitary is the least expensive weapon. Where rows with green but no red cost exist, the INS/GPS guided weapon is the least expensive option. And where a red cost exists, independent of whether or not a green cost exists, the seeker-guided option represents the least-cost approach. These "least-cost" cases are the ones that are presented in the "maps" (Figures 3-3 and 3-4 in Chapter 3 of the main report).

Another thing to note is the lack of sensitivity of the least-cost results to either precise weapon UPCs or transportation and support costs. In the case of the latter, over the included range of a factor of two ($500 to $1,000), the least-cost approaches remain constant. For the $500, $15,000 and $35,000 UPCs of the three weapon options, examination of the spreadsheet's break-even costs will indicate that in the vast majority of cases, once a break-even cost exceeds either the $15,000 or $35,000 assumed cost of the two guided weapons, it exceeds it by a large margin. This indicates that except for perhaps a boundary case shifting occasionally by a few meters of TLE, the overall results are largely independent of the details of assumed UPC.

Two sets of tables are included below. Table E-1 includes the effect of the forward observer on the unguided unitary. Table E-2 is without the forward observer effect.

Table E-1
Cost-to-Kill Spreadsheet Results
(Including Forward Observer Impact)

Cost of Un-guided		$500	Cost of Guided Unit		$15,000	Cost of Guid Disc.		$35,000	
Truck	0.1								
TLE	# unguid	guid uni-tary	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	5	1	$4,500	$5,500	$6,500	1	$15,000	$15,000	$15,000
5	5	1	$4,500	$5,500	$6,500	1	$15,000	$15,000	$15,000
10	5	1	$4,500	$5,500	$6,500	1	$15,000	$15,000	$15,000
15	5	1	$4,500	$5,500	$6,500	1	$15,000	$15,000	$15,000
20	5	1	$4,500	$5,500	$6,500	1	$15,000	$15,000	$15,000
25	5	1	$4,500	$5,500	$6,500	1	$15,000	$15,000	$15,000
30	6	1	$5,500	$6,750	$8,000	1	$15,000	$15,000	$15,000
UPC	0.1								
TLE	# unguid	guid uni-tary	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	57	1	**$56,500**	**$70,500**	**$84,500**	1	$15,000	$15,000	$15,000
5	57	1	**$56,500**	**$70,500**	**$84,500**	1	$15,000	$15,000	$15,000
10	58	2	**$28,500**	**$35,500**	**$42,500**	1	$30,500	$30,750	$31,000
15	62	3	**$20,167**	**$25,083**	**$30,000**	1	**$46,000**	**$46,500**	**$47,000**
20	67	5	$12,900	**$16,000**	**$19,100**	1	**$77,000**	**$78,000**	**$79,000**
25	67	9	$6,944	$8,556	$10,167	1	**$139,000**	**$141,000**	**$143,000**
30	75	16	$4,188	$5,109	$6,031	1	**$247,500**	**$251,250**	**$255,000**
Tank	0.1								
TLE	#unguid	guid unit	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	71	1	**$70,500**	**$88,000**	**$105,500**	1	$15,000	$15,000	$15,000
5	71	2	**$35,000**	**$43,625**	**$52,250**	1	$30,500	$30,750	$31,000
10	74	3	**$24,167**	**$30,083**	**$36,000**	1	**$46,000**	**$46,500**	**$47,000**
15	78	4	**$19,000**	**$23,625**	**$28,250**	1	**$61,500**	**$62,250**	**$63,000**
20	78	7	$10,643	$13,179	**$15,714**	1	**$108,000**	**$109,500**	**$111,000**
25	83	13	$5,885	$7,231	$8,577	1	**$201,000**	**$204,000**	**$207,000**
30	85	24	$3,042	$3,677	$4,313	1	**$371,500**	**$377,250**	**$383,000**
Truck	0.3								
	#unguid	guid unit	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	17	1	**$16,500**	**$20,500**	**$24,500**	1	$15,000	$15,000	$15,000
5	17	1	**$16,500**	**$20,500**	**$24,500**	1	$15,000	$15,000	$15,000
10	17	1	**$16,500**	**$20,500**	**$24,500**	1	$15,000	$15,000	$15,000
15	17	1	**$16,500**	**$20,500**	**$24,500**	1	$15,000	$15,000	$15,000
20	17	2	$8,000	$9,875	$11,750	1	$30,500	$30,750	$31,000
25	19	2	$9,000	$11,125	$13,250	1	$30,500	$30,750	$31,000
30	21	3	$6,500	$8,000	$9,500	1	**$46,000**	**$46,500**	**$47,000**
UPC	0.3								
	#unguid	guid unit	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	278	3	**$92,167**	**$115,083**	**$138,000**	1	**$46,000**	**$46,500**	**$47,000**
5	281	4	**$69,750**	**$87,063**	**$104,375**	1	**$61,500**	**$62,250**	**$63,000**
10	291	7	**$41,071**	**$51,214**	**$61,357**	1	**$108,000**	**$109,500**	**$111,000**
15	309	16	**$18,813**	**$23,391**	**$27,969**	1	**$247,500**	**$251,250**	**$255,000**
20	333	52	$5,904	$7,255	$8,606	1	**$805,500**	**$818,250**	**$831,000**
25	372	274	$858	$947	$1,036	1	**$4,246,500**	**$4,314,750**	**$4,383,000**
30	410	410	$500	$500	$500	1	**$6,354,500**	**$6,456,750**	**$6,559,000**

Tank	0.3								
	#unguid	#guid uni	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	327	4	**$81,250**	**$101,438**	**$121,625**	1	**$61,500**	**$62,250**	**$63,000**
5	327	5	**$64,900**	**$81,000**	**$97,100**	1	**$77,000**	**$78,000**	**$79,000**
10	347	10	**$34,200**	**$42,625**	**$51,050**	1	**$154,500**	**$156,750**	**$159,000**
15	372	24	**$15,000**	**$18,625**	**$22,250**	1	**$371,500**	**$377,250**	**$383,000**
20	397	89	$3,961	$4,826	$5,691	1	**$1,379,000**	**$1,401,000**	**$1,423,000**
25	445	445	$500	$500	$500	1	**$6,897,000**	**$7,008,000**	**$7,119,000**
30	502	502	$500	$500	$500	1	**$7,780,500**	**$7,905,750**	**$8,031,000**
Truck	0.8								
	#unguid	guid unit	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	520	2	**$259,500**	**$324,250**	**$389,000**	1	$30,500	$30,750	$31,000
5	535	2	**$267,000**	**$333,625**	**$400,250**	1	$30,500	$30,750	$31,000
10	593	3	**$197,167**	**$246,333**	**$295,500**	1	**$46,000**	**$46,500**	**$47,000**
15	653	6	**$108,333**	**$135,292**	**$162,250**	1	**$92,500**	**$93,750**	**$95,000**
20	783	15	**$51,700**	**$64,500**	**$77,300**	1	**$232,000**	**$235,500**	**$239,000**
25	868	19	**$45,184**	**$56,355**	**$67,526**	1	**$294,000**	**$298,500**	**$303,000**
30	1100	22	**$49,500**	**$61,750**	**$74,000**	1	**$340,500**	**$345,750**	**$351,000**
UPC	0.8								
	#unguid	guid unit	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	1000	3	**$332,833**	**$415,917**	**$499,000**	1	**$46,000**	**$46,500**	**$47,000**
5	2000	4	**$499,500**	**$624,250**	**$749,000**	1	**$61,500**	**$62,250**	**$63,000**
10	3000	7	**$428,071**	**$534,964**	**$641,857**	1	**$108,000**	**$109,500**	**$111,000**
15	4000	16	**$249,500**	**$311,750**	**$374,000**	1	**$247,500**	**$251,250**	**$255,000**
20	5000	52	**$95,654**	**$119,442**	**$143,231**	1	**$805,500**	**$818,250**	**$831,000**
25	8000	274	**$28,697**	**$35,746**	**$42,796**	1	**$4,246,500**	**$4,314,750**	**$4,383,000**
30	12000	1000	$11,500	$14,250	**$17,000**	1	**$15,499,500**	**$15,749,250**	**$15,999,000**
Tank	0.8								
	#unguid	#guid uni	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	1000	25	**$39,500**	**$49,250**	**$59,000**	1	**$387,000**	**$393,000**	**$399,000**
5	2000	51	**$38,716**	**$48,270**	**$57,824**	1	**$790,000**	**$802,500**	**$815,000**
10	3000	635	$4,224	$5,156	$6,087	1	**$9,842,000**	**$10,000,500**	**$10,159,000**
15	4000	1000	$3,500	$4,250	$5,000	1	**$15,499,500**	**$15,749,250**	**$15,999,000**
20	5000	1000	$4,500	$5,500	$6,500	1	**$15,499,500**	**$15,749,250**	**$15,999,000**
25	7000	1000	$6,500	$8,000	$9,500	1	**$15,499,500**	**$15,749,250**	**$15,999,000**
30	8000	1000	$7,500	$9,250	$11,000	1	**$15,499,500**	**$15,749,250**	**$15,999,000**

Cost of Unguided		**$500**	Cost of Guided Unit		$15,000	**Cost of Guid Disc.**		$35,000	
Truck	**0.1**								
TLE	**# unguid using FO**	**guid unitary**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
5	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
10	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
15	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
20	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
25	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
30	**3**	**1**	$2,500	$3,000	$3,500	**1**	$15,000	$15,000	$15,000
UPC	**0.1**								
TLE	**# unguid using FO**	**guid unitary**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**27**	**1**	**$26,500**	**$33,000**	**$39,500**	**1**	$15,000	$15,000	$15,000
5	**27**	**1**	**$26,500**	**$33,000**	**$39,500**	**1**	$15,000	$15,000	$15,000
10	**27**	**2**	$13,000	**$16,125**	**$19,250**	**1**	$30,500	$30,750	$31,000
15	**27**	**3**	$8,500	$10,500	$12,500	**1**	**$46,000**	**$46,500**	**$47,000**
20	**27**	**5**	$4,900	$6,000	$7,100	**1**	**$77,000**	**$78,000**	**$79,000**
25	**27**	**9**	$2,500	$3,000	$3,500	**1**	**$139,000**	**$141,000**	**$143,000**
30	**27**	**16**	$1,188	$1,359	$1,531	**1**	**$247,500**	**$251,250**	**$255,000**
Tank	**0.1**								
TLE	**# unguid using FO**	**guid unitary**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**31**	**1**	**$30,500**	**$38,000**	**$45,500**	**1**	$15,000	$15,000	$15,000
5	**31**	**2**	**$15,000**	**$18,625**	**$22,250**	**1**	$30,500	$30,750	$31,000
10	**31**	**3**	$9,833	$12,167	$14,500	**1**	**$46,000**	**$46,500**	**$47,000**
15	**31**	**4**	$7,250	$8,938	$10,625	**1**	**$61,500**	**$62,250**	**$63,000**
20	**31**	**7**	$3,929	$4,786	$5,643	**1**	**$108,000**	**$109,500**	**$111,000**
25	**31**	**13**	$1,885	$2,231	$2,577	**1**	**$201,000**	**$204,000**	**$207,000**
30	**31**	**24**	$792	$865	$938	**1**	**$371,500**	**$377,250**	**$383,000**
Truck	**0.3**								
TLE	**# unguid using FO**	**guid unitary**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**7**	**1**	$6,500	$8,000	$9,500	**1**	$15,000	$15,000	$15,000
5	**7**	**1**	$6,500	$8,000	$9,500	**1**	$15,000	$15,000	$15,000
10	**7**	**1**	$6,500	$8,000	$9,500	**1**	$15,000	$15,000	$15,000
15	**7**	**1**	$6,500	$8,000	$9,500	**1**	$15,000	$15,000	$15,000
20	**7**	**2**	$3,000	$3,625	$4,250	**1**	$30,500	$30,750	$31,000
25	**7**	**2**	$3,000	$3,625	$4,250	**1**	$30,500	$30,750	$31,000
30	**7**	**3**	$1,833	$2,167	$2,500	**1**	**$46,000**	**$46,500**	**$47,000**
UPC	**0.3**								
TLE	**# unguid using FO**	**guid unitary**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**95**	**3**	**$31,167**	**$38,833**	**$46,500**	**1**	**$46,000**	**$46,500**	**$47,000**
5	**95**	**4**	**$23,250**	**$28,938**	**$34,625**	**1**	**$61,500**	**$62,250**	**$63,000**
10	**95**	**7**	$13,071	**$16,214**	**$19,357**	**1**	**$108,000**	**$109,500**	**$111,000**
15	**95**	**16**	$5,438	$6,672	$7,906	**1**	**$247,500**	**$251,250**	**$255,000**
20	**95**	**52**	$1,327	$1,534	$1,740	**1**	**$805,500**	**$818,250**	**$831,000**
25	**95**	**274**	($153)	($317)	($480)	**1**	**$4,246,500**	**$4,314,750**	**$4,383,000**
30	**95**	**410**	($268)	($460)	($652)	**1**	**$6,354,500**	**$6,456,750**	**$6,559,000**

Table E-1
Cost-to-Kill Spreadsheet Results
(Including Forward Observer Impact)

Tank	0.3								
TLE	# unguid using FO	guid unitary	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	116	4	$28,500	$35,500	$42,500	1	$61,500	$62,250	$63,000
5	116	5	$22,700	$28,250	$33,800	1	$77,000	$78,000	$79,000
10	116	10	$11,100	$13,750	$16,400	1	$154,500	$156,750	$159,000
15	116	24	$4,333	$5,292	$6,250	1	$371,500	$377,250	$383,000
20	116	89	$803	$879	$955	1	$1,379,000	$1,401,000	$1,423,000
25	116	445	($239)	($424)	($609)	1	$6,897,000	$7,008,000	$7,119,000
30	116	502	($269)	($461)	($653)	1	$7,780,500	$7,905,750	$8,031,000

Truck	0.8								
TLE	# unguid using FO	guid unitary	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	45	2	$22,000	$27,375	$32,750	1	$30,500	$30,750	$31,000
5	45	2	$22,000	$27,375	$32,750	1	$30,500	$30,750	$31,000
10	45	3	$14,500	$18,000	$21,500	1	$46,000	$46,500	$47,000
15	45	6	$7,000	$8,625	$10,250	1	$92,500	$93,750	$95,000
20	45	15	$2,500	$3,000	$3,500	1	$232,000	$235,500	$239,000
25	45	19	$1,868	$2,211	$2,553	1	$294,000	$298,500	$303,000
30	45	22	$1,545	$1,807	$2,068	1	$340,500	$345,750	$351,000

UPC	0.8								
TLE	# unguid using FO	guid unitary	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	898	3	$298,833	$373,417	$448,000	1	$46,000	$46,500	$47,000
5	898	4	$224,000	$279,875	$335,750	1	$61,500	$62,250	$63,000
10	898	7	$127,786	$159,607	$191,429	1	$108,000	$109,500	$111,000
15	898	16	$55,625	$69,406	$83,188	1	$247,500	$251,250	$255,000
20	898	52	$16,769	$20,837	$24,904	1	$805,500	$818,250	$831,000
25	898	274	$2,777	$3,347	$3,916	1	$4,246,500	$4,314,750	$4,383,000
30	898	1000	$398	$373	$347	1	$15,499,500	$15,749,250	$15,999,000

Tank	0.8								
TLE	# unguid using FO	guid unitary	$500	$750	$1,000	disc guid	$500	$750	$1,000
0	1000	25	$39,500	$49,250	$59,000	1	$387,000	$393,000	$399,000
5	1000	51	$19,108	$23,760	$28,412	1	$790,000	$802,500	$815,000
10	1000	635	$1,075	$1,219	$1,362	1	$9,842,000	$10,000,500	$10,159,000
15	1000	1000	$500	$500	$500	1	$15,499,500	$15,749,250	$15,999,000
20	1000	1000	$500	$500	$500	1	$15,499,500	$15,749,250	$15,999,000
25	1000	1000	$500	$500	$500	1	$15,499,500	$15,749,250	$15,999,000
30	1000	1000	$500	$500	$500	1	$15,499,500	$15,749,250	$15,999,000

Table E-2
Cost-to-Kill Spreadsheet Results
(Without Forward Observer Impact)

Cost of Unguided		**$500**	Cost of Guided Unit		$15,000	**Cost of Guid Disc.**		$35,000		
Truck	**0.1**									
TLE	**# unguid**	**guid unita**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000	
0	**5**	**1**	$4,500	$5,500	$6,500	**1**	$15,000	$15,000	$15,000	
5	**5**	**1**	$4,500	$5,500	$6,500	**1**	$15,000	$15,000	$15,000	
10	**5**	**1**	$4,500	$5,500	$6,500	**1**	$15,000	$15,000	$15,000	
15	**5**	**1**	$4,500	$5,500	$6,500	**1**	$15,000	$15,000	$15,000	
20	**5**	**1**	$4,500	$5,500	$6,500	**1**	$15,000	$15,000	$15,000	
25	**5**	**1**	$4,500	$5,500	$6,500	**1**	$15,000	$15,000	$15,000	
30	**6**	**1**	$5,500	$6,750	$8,000	**1**	$15,000	$15,000	$15,000	
UPC	**0.1**									
TLE	**# unguid**	**guid unita**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000	
0	**57**	**1**	**$56,500**	**$70,500**	**$84,500**	**1**	$15,000	$15,000	$15,000	
5	**57**	**1**	**$56,500**	**$70,500**	**$84,500**	**1**	$15,000	$15,000	$15,000	
10	**58**	**2**	**$28,500**	**$35,500**	**$42,500**	**1**	$30,500	$30,750	$31,000	
15	**62**	**3**	**$20,167**	**$25,083**	**$30,000**	**1**	**$46,000**	**$46,500**	**$47,000**	
20	**67**	**5**	$12,900	**$16,000**	**$19,100**	**1**	**$77,000**	**$78,000**	**$79,000**	
25	**67**	**9**	$6,944	$8,556	$10,167	**1**	**$139,000**	**$141,000**	**$143,000**	
30	**75**	**16**	$4,188	$5,109	$6,031	**1**	**$247,500**	**$251,250**	**$255,000**	
Tank	**0.1**									
TLE	**#unguid**	**guid unit**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000	
0	**71**	**1**	**$70,500**	**$88,000**	**$105,500**	**1**	$15,000	$15,000	$15,000	
5	**71**	**2**	**$35,000**	**$43,625**	**$52,250**	**1**	$30,500	$30,750	$31,000	
10	**74**	**3**	**$24,167**	**$30,083**	**$36,000**	**1**	**$46,000**	**$46,500**	**$47,000**	
15	**78**	**4**	**$19,000**	**$23,625**	**$28,250**	**1**	**$61,500**	**$62,250**	**$63,000**	
20	**78**	**7**	$10,643	$13,179	**$15,714**	**1**	**$108,000**	**$109,500**	**$111,000**	
25	**83**	**13**	$5,885	$7,231	$8,577	**1**	**$201,000**	**$204,000**	**$207,000**	
30	**85**	**24**	$3,042	$3,677	$4,313	**1**	**$371,500**	**$377,250**	**$383,000**	
Truck	**0.3**									
	#unguid	**guid unit**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000	
0	**17**	**1**	**$16,500**	**$20,500**	**$24,500**	**1**	$15,000	$15,000	$15,000	
5	**17**	**1**	**$16,500**	**$20,500**	**$24,500**	**1**	$15,000	$15,000	$15,000	
10	**17**	**1**	**$16,500**	**$20,500**	**$24,500**	**1**	$15,000	$15,000	$15,000	
15	**17**	**1**	**$16,500**	**$20,500**	**$24,500**	**1**	$15,000	$15,000	$15,000	
20	**17**	**2**	$8,000	$9,875	$11,750	**1**	$30,500	$30,750	$31,000	
25	**19**	**2**	$9,000	$11,125	$13,250	**1**	$30,500	$30,750	$31,000	
30	**21**	**3**	$6,500	$8,000	$9,500	**1**	**$46,000**	**$46,500**	**$47,000**	
UPC	**0.3**									
	#unguid	**guid unit**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000	
0	**278**	**3**	**$92,167**	**$115,083**	**$138,000**	**1**	**$46,000**	**$46,500**	**$47,000**	
5	**281**	**4**	**$69,750**	**$87,063**	**$104,375**	**1**	**$61,500**	**$62,250**	**$63,000**	
10	**291**	**7**	**$41,071**	**$51,214**	**$61,357**	**1**	**$108,000**	**$109,500**	**$111,000**	
15	**309**	**16**	**$18,813**	**$23,391**	**$27,969**	**1**	**$247,500**	**$251,250**	**$255,000**	
20	**333**	**52**	$5,904	$7,255	$8,606	**1**	**$805,500**	**$818,250**	**$831,000**	
25	**372**	**274**	$858	$947	$1,036	**1**	**$4,246,500**	**$4,314,750**	**$4,383,000**	
30	**410**	**410**	$500	$500	$500	**1**	**$6,354,500**	**$6,456,750**	**$6,559,000**	

Table E-2
Cost-to-Kill Spreadsheet Results
(Without Forward Observer Impact)

Tank	**0.3**								
	#unguid	**#guid uni**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**327**	**4**	**$81,250**	**$101,438**	**$121,625**	**1**	**$61,500**	**$62,250**	**$63,000**
5	**327**	**5**	**$64,900**	**$81,000**	**$97,100**	**1**	**$77,000**	**$78,000**	**$79,000**
10	**347**	**10**	**$34,200**	**$42,625**	**$51,050**	**1**	**$154,500**	**$156,750**	**$159,000**
15	**372**	**24**	**$15,000**	**$18,625**	**$22,250**	**1**	**$371,500**	**$377,250**	**$383,000**
20	**397**	**89**	$3,961	$4,826	$5,691	**1**	**$1,379,000**	**$1,401,000**	**$1,423,000**
25	**445**	**445**	$500	$500	$500	**1**	**$6,897,000**	**$7,008,000**	**$7,119,000**
30	**502**	**502**	$500	$500	$500	**1**	**$7,780,500**	**$7,905,750**	**$8,031,000**
Truck	**0.8**								
	#unguid	**guid unit**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**520**	**2**	**$259,500**	**$324,250**	**$389,000**	**1**	$30,500	$30,750	$31,000
5	**535**	**2**	**$267,000**	**$333,625**	**$400,250**	**1**	$30,500	$30,750	$31,000
10	**593**	**3**	**$197,167**	**$246,333**	**$295,500**	**1**	**$46,000**	**$46,500**	**$47,000**
15	**653**	**6**	**$108,333**	**$135,292**	**$162,250**	**1**	**$92,500**	**$93,750**	**$95,000**
20	**783**	**15**	**$51,700**	**$64,500**	**$77,300**	**1**	**$232,000**	**$235,500**	**$239,000**
25	**868**	**19**	**$45,184**	**$56,355**	**$67,526**	**1**	**$294,000**	**$298,500**	**$303,000**
30	**1100**	**22**	**$49,500**	**$61,750**	**$74,000**	**1**	**$340,500**	**$345,750**	**$351,000**
UPC	**0.8**								
	#unguid	**guid unit**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**1000**	**3**	**$332,833**	**$415,917**	**$499,000**	**1**	**$46,000**	**$46,500**	**$47,000**
5	**2000**	**4**	**$499,500**	**$624,250**	**$749,000**	**1**	**$61,500**	**$62,250**	**$63,000**
10	**3000**	**7**	**$428,071**	**$534,964**	**$641,857**	**1**	**$108,000**	**$109,500**	**$111,000**
15	**4000**	**16**	**$249,500**	**$311,750**	**$374,000**	**1**	**$247,500**	**$251,250**	**$255,000**
20	**5000**	**52**	**$95,654**	**$119,442**	**$143,231**	**1**	**$805,500**	**$818,250**	**$831,000**
25	**8000**	**274**	**$28,697**	**$35,746**	**$42,796**	**1**	**$4,246,500**	**$4,314,750**	**$4,383,000**
30	**12000**	**1000**	$11,500	$14,250	**$17,000**	**1**	**$15,499,500**	**$15,749,250**	**$15,999,000**
Tank	**0.8**								
	#unguid	**#guid uni**	$500	$750	$1,000	**disc guid**	$500	$750	$1,000
0	**1000**	**25**	**$39,500**	**$49,250**	**$59,000**	**1**	**$387,000**	**$393,000**	**$399,000**
5	**2000**	**51**	**$38,716**	**$48,270**	**$57,824**	**1**	**$790,000**	**$802,500**	**$815,000**
10	**3000**	**635**	$4,224	$5,156	$6,087	**1**	**$9,842,000**	**$10,000,500**	**$10,159,000**
15	**4000**	**1000**	$3,500	$4,250	$5,000	**1**	**$15,499,500**	**$15,749,250**	**$15,999,000**
20	**5000**	**1000**	$4,500	$5,500	$6,500	**1**	**$15,499,500**	**$15,749,250**	**$15,999,000**
25	**7000**	**1000**	$6,500	$8,000	$9,500	**1**	**$15,499,500**	**$15,749,250**	**$15,999,000**
30	**8000**	**1000**	$7,500	$9,250	$11,000	**1**	**$15,499,500**	**$15,749,250**	**$15,999,000**

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APPENDIX F. ACRONYMS

3ID	3rd Infantry Division
ABCCC	Airborne Battlefield Command and Control Center
ACTD	Advanced Concept Technology Demonstration
ADOCS	Automated Deep Operations Coordination System
AFATDS	Advanced Field Artillery Tactical Data System
AJ	anti-jam
ALT	acquisition, logistics, and technology
AMSTE	affordable moving surface target engagement
AOF	angle of fall
AOR	area of responsibility
APC	armored personnel carrier
ASA	Assistant Secretary of the Army
ASCS	Air Support Control Section
ASN	Assistant Secretary of the Navy
ASOC	Air Support Operations Center
AT	advanced technology
BCD	Battlefield Coordination Detachment
BCL	Battlefield Coordination Line
BDA	battle damage assessment
BFIST	Bradley Fire Support Team
BFSA	Blue Force Situational Awareness
BFT	Blue Force Tracking
BMC^3	battle management command, control, and communications
BPS	bits per second
C^2	command and control
C^3	command, control, and communications
C^4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CAS	close air support
CATF	Commander, Amphibious Task Force
CC&D	camouflage, concealment, and deception
CEP	circular error probability
CGIMU	Common Guidance Inertial Measurement Unit
CID	combat identification
CLF	Commander, Landing Force
CM/CB	counter-mortar/counter-battery
COCOM	Combatant Commander
CSW	coordinate-seeking weapons
CTP	common targeting picture
DFB	division forward boundary
DMPI	designated mean point of impact
DOCC	Deep Operations Coordination Cell
DoD	Department of Defense
DPPDB	Digital Point Positioning Database

DSB	Defense Science Board
ECM	electronic counter measures
EO	electro-optical
ERM	Extended Range Munition
ERGM	Extended Range Guided Munition
FBCB2	Force XXI Battle Command Brigade Below
FCS	Future Combat System
FD	fractional damage
FIOPs	Family of Common Operation Pictures
FLIR	forward looking infrared
FLOT	forward line of own troops
FO	forward observer
FPA	focal plane array
FSCC	Fire Support Coordination Center
FSCL	Fire Support Coordination Line
FSCOORDs	Fire Support Coordinators
FSV	fire support vehicles
G	G force
GB	gigabyte
GIF	Guided Integrated Fuze
GMLRS	Guided Multiple Rocket Launch System
GN&C	guidance, navigation, and control
GPS	Global Positioning System
G/VLLD	Ground/Vehicular Laser Locator Designator
HE	high energy explosive
$HIDAC^2$	High Density Airspace Control Zone
ID	target identification
IFF	identification friend or foe
IFS	integrated fire support
IMU	inertial measurement units
INS	inertial navigation system
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
JAOC	Joint Air Operations Center
$JBMC^2$	Joint Battle Management Command and Control
JCAS	Joint Close Air Support
JDAM	Joint Direct Attack Munition
JEFX	Joint Expeditionary Force Experiment
JFACC	Joint Force Air Component Commander
JFC	Joint Force Commander
JFCOM	Joint Forces Command
JIFSS	Joint Integrated Fire Support System
JIFSS	Joint Integrated Fire Support System
JMEM	Joint Munitions Effectiveness Manual
KE	kinetic energy
KB	kilobit

kBPS	kilobits per second
LADAR	laser detection and ranging
LAM	loitering air missile
LLDR	lightweight LASER designator rangefinder
LRSS	long-range scout sight
MDA	model drive architecture
MEMS	micro-electro mechanical
MIDB	military intelligence database
MRAAS	multi-role armament and ammunition system
MRR	minimum risk route
m/s	meters per second
MTI	moving target indicator
NCA	National Command Authority
NCTR	non-cooperative target recognition
NGA	National Geo-spatial Intelligence Agency
NII	networks and information integration
NSFC	naval surface fire control
NTACS	Navy Tactical Air Control System
NTM	National Technical Means
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OMG	object modeling group
OPCON	operational control
OSD	Office of the Secretary of Defense
PAAs	position artillery areas
PAH	position area hazards
PGMM	Precision Guided Mortar Munition
PIM	Platform Independent Model
PMFs	probability mass functions
PSI	platform specific implementation
R&D	research and development
RDA	research development and acquisition
RF	radio frequency
ROA	Restricted Operations Area
ROE	rules of engagement
ROZ	Restricted Operations Zone
S&T	science and technology
SA	situation awareness
SAAFR	standard use army aircraft flight route
SAASM	selected availability anti-spoofing module
SACC	Supporting Arms Coordination Center
SAR	Synthetic Aperture Radar
SFCP	Shore Fire Control Party
SIAP	single integrated air picture
SIGINT	signals intelligence
SIGP	single integrated ground picture

SMTI	surface moving target indicator
SOCCORD	Special Operations Coordination Element
TACP	tactical air control party
TBMCS	theater core battle management system
TCEP	total circular error probability
TEL	transporter/erector/launcher
TLE	target location error
TOR	Terms of Reference
TOT	time on target
TTP	tactics, techniques, and procedures
TUAV	tactical unmanned aerial vehicle
UAV	unmanned aerial vehicles
UML	universal modeling language
UPC	unit production cost
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USMFT	United States message text format
WDE	weapon delivery error